

2005

## Implementing best practice protocols for occupational hygiene monitoring

Hayden Wing  
*Edith Cowan University*

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IMPLEMENTING BEST PRACTICE PROTOCOLS FOR  
OCCUPATIONAL HYGIENE MONITORING

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1<sup>ST</sup> DECEMBER 2005

## USE OF THESIS

The Use of Thesis statement is not included in this version of the thesis.

## **ABSTRACT**

This thesis outlines the results of an occupational hygiene monitoring program implemented at Minara Resources' Murrin Murrin mine site.

The research was conducted as part of a collaborative agreement between Edith Cowan University and Minara Resources, the title of which was "Establishing best practice protocols in the management of occupational and environmental health in a high risk mining and ore processing environment".

To form the basis of this research it was hypothesised that chemical hazards had not been adequately identified, that existing occupational hygiene monitoring programs did not adequately quantify employee exposures to these hazards, and that the implementation of a comprehensive hazard identification and monitoring program would greatly improve the capacity to quantify the health risks posed to employees.

In order to limit the scale of this project, the research was restricted to employees of Minara Resources who were involved in normal production activities. Contractors and maintenance personnel were excluded.

In working through these hypotheses, a literature review concentrating on the identification of hazards, the design of monitoring programs, and the subsequent statistical analysis of the results was conducted.

Following this review, the various production areas of the processing plant were consulted to identify the chemical hazards, and a monitoring program was implemented over a period of approximately four months.

An analysis of the results showed that the level of understanding relating to health risks was greatly improved. These results will therefore enable management to accurately direct resources at those hazards requiring increased levels of control. As a by-product of this increased knowledge, Murrin Murrin has also achieved a higher level of compliance with the Mines Safety and Inspection Act 1994.

Management now has an opportunity to expand upon this work and include contactors, and those involved in maintenance work, in future hazard identification and monitoring programs.

## **DECLARATION**

I certify that this thesis does not, to the best of my knowledge and belief:

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- (ii) contain any material previously published or written by another person except where due reference is made in the text; or
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1<sup>st</sup> December 2005

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- Jacques Oosthuizen – for establishing the collaborative agreement under which this study was conducted, and for acting as my research supervisor;
- Minara Resources – for agreeing to the collaborative agreement and supporting the research outlined in this thesis.
- David Richardson (ECU) – for setting up, collecting and gathering information on many of the samples taken under this monitoring program.



## TABLE OF CONTENTS

<b>Use of Thesis .....</b>	<b>ii</b>
<b>Abstract.....</b>	<b>iii</b>
<b>Declaration.....</b>	<b>v</b>
<b>Acknowledgements .....</b>	<b>vi</b>
<b>List of Tables .....</b>	<b>ix</b>
<b>CHAPTER 1 – Introduction .....</b>	<b>1</b>
Problem Statement.....	1
Aim and Scope.....	1
Overview of the Study .....	2
<b>Chapter 2 – Background Information .....</b>	<b>3</b>
Legislative Overview .....	3
Exposure Standards.....	4
Basic Principles of Exposure Assessment .....	7
Identification of Atmospheric Contaminants.....	8
Preliminary Assessment.....	9
Conduct Atmospheric Monitoring .....	9
Analysis and Interpretation of Results .....	10
Production Process.....	11
Historical Data .....	14
Potential Health Effects .....	15
Nickel Dusts.....	15
Cobalt Dusts.....	16
Sulphuric Acid Mist.....	17
Hydrogen Sulphide .....	18
Sulphur Dioxide .....	18
Ammonia.....	19
<b>Chapter 3 – Research Design .....</b>	<b>20</b>
Hypothesis 1 - Chemical Hazards at Murrin Murrin Had Not Been Adequately Identified.....	20
Hypothesis 2 - The occupational hygiene monitoring protocols did not adequately quantify worker exposures to these chemical hazards.....	22
Hypothesis 3 - The implementation of a comprehensive hazard identification and monitoring program, will greatly improve capacity to quantify health risks of exposed workers.....	22
<b>Chapter 4 – Results.....</b>	<b>42</b>

Hypothesis Part 1 - Chemical Hazards at Murrin Murrin Had Not Been Adequately Identified.....	42
Hypothesis Part 2 - The current occupational hygiene monitoring protocols did not adequately quantify worker exposures to these chemical hazards.....	46
Hypothesis Part 3 - The implementation of a comprehensive hazard identification and monitoring program, would greatly improve capacity to quantify health risks of exposed workers. ....	99
<b>Chapter 5 – Discussion and Conclusions .....</b>	<b>113</b>
Hypothesis Part 1 - Chemical Hazards at Murrin Murrin Have Not Been Adequately Identified.....	113
Hypothesis Part 2 - The current occupational hygiene monitoring protocols do not adequately quantify worker exposures to these chemical hazards.....	114
Hypothesis Part 3 - The implementation of a comprehensive hazard identification and monitoring program, will greatly improve capacity to quantify health risks of exposed workers.....	114
Utilities – 4100/5100 Operators.....	117
Ore Leach – 3100 Operators.....	120
Ore Leach – 3200, 3300 and 3400/3510 Operators .....	122
Refinery – 3500 Operators.....	124
Refinery – 3600 Operators.....	125
Refinery – 3700 Operators.....	126
Refinery – 3700 Furnace Operators .....	127
Refinery – Packaging Operators .....	127
Refinery – 3800 Operators.....	129
Refinery – 3900 Operators.....	129
Refinery – 5900 Operator .....	131
General Discussion on Unacceptable SEGs .....	132
Recommended Future Sampling Programs .....	134
General Discussion on the Success of the Monitoring Program.....	138
<b>List of References.....</b>	<b>141</b>
<b>Appendix A – Monitoring Logsheets.....</b>	<b>145</b>
<b>Appendix B – Utilities Monitoring Results.....</b>	<b>156</b>
<b>Appendix C – Ore Leach monitoring results .....</b>	<b>159</b>
<b>Appendix D – Refinery Monitoring Results .....</b>	<b>168</b>

## LIST OF TABLES

Table 1 - <i>CONTAM Quota for Murrin Murrin</i> .....	14
Table 2 - <i>Number of Samples Required to Ensure a 90% Probability of Sampling an Individual with an Exposure in the Highest 10% of all Exposures</i> .....	24
Table 3 - <i>The Required Number of Samples to Test Compliance with an Exposure Standard at a 95% Significance Level and 90% Power</i> .....	33
Table 4 - <i>The Maximum Fraction of Samples (1-f) which are Predicted to Exceed the Exposure Standard</i> .....	39
Table 5 - <i>List of Chemicals Identified in Utilities</i> .....	43
Table 6 - <i>List of Chemicals Identified in Ore Leach</i> .....	44
Table 7 - <i>List of Chemicals Identified in Refinery</i> .....	45
Table 8a - <i>Utilities – Justification for Monitoring Program</i> .....	47
Table 8b - <i>Utilities – Justification for Monitoring Program</i> .....	55
Table 9a - <i>Ore Leach – Justification for Monitoring Program</i> .....	62
Table 9b - <i>Ore Leach – Justification for Monitoring Program</i> .....	70
Table 10a - <i>Refinery – Justification for Monitoring Program</i> .....	76
Table 10b - <i>Refinery – Justification for Monitoring Program</i> .....	86
Table 11 - <i>Chemicals Identified in Utilities for which Atmospheric Monitoring is Required</i> .....	97
Table 12 - <i>Chemicals Identified in Ore Leach for which Atmospheric Monitoring is Required</i> .....	98
Table 13 - <i>Chemicals Identified in Refinery for which Atmospheric Monitoring is Required</i> .....	99
Table 14 - <i>Statistical Summary of Results of Inhalable Dust, Respirable Dust and Sulphuric Acid Mist Monitoring Conducted in Utilities</i> .....	100
Table 15 - <i>Statistical Summary of Results of Inhalable Dust Monitoring Conducted in Ore Leach</i> .....	102
Table 16 - <i>Statistical Summary of Results of Sulphuric Acid Mist Monitoring Conducted in Ore Leach</i> .....	103
Table 17a - <i>Statistical Summary of Results of Inhalable Dust Monitoring Conducted in Refinery</i> .....	105
Table 17b - <i>Statistical Summary of Results of Inhalable Dust Monitoring Conducted in Refinery (continued)</i> .....	106
Table 18 - <i>Statistical Summary of Results of Nickel Dust Monitoring Conducted in Refinery</i> .....	107
Table 19 - <i>Statistical Summary of Results of Cobalt Dust Monitoring Conducted in Refinery</i> .....	108
Table 20 - <i>Statistical Summary of Results of Ammonia Monitoring Conducted in Refinery</i> .....	109
Table 21 - <i>Statistical Summary of Results of Solvent Monitoring (Total VOC) Conducted in Refinery</i> .....	110
Table 22 - <i>Total Additive Exposures for Operators Working in Utilities</i> .....	111
Table 23 - <i>Total Additive Exposures for Operators Working in Ore Leach</i> .....	111
Table 24 - <i>Total Additive Exposures for Operators Working in Refinery</i> .....	112
Table 25 - <i>Exposure Standard Adjustments used in this Study</i> .....	117

Table 26 - <i>The Minimum Time to be Spent on Regularly Monitoring Personal Exposure</i> .....	135
Table 27 - <i>Recommended Future Sampling Program</i> .....	136
Table 28 - <i>Inhalable Dust Results for 4100/5100 Operators</i> .....	156
Table 29 - <i>Respirable Dust Results for 4100/5100 Operators</i> .....	156
Table 30 - <i>Sulphuric Acid Mist Results for 4100/5100 Operators</i> .....	157
Table 31 - <i>Hydrogen Sulphide Results for 4100/5100 Operators</i> .....	157
Table 32 - <i>Sulphur Dioxide Results for 4100/5100 Operators</i> .....	158
Table 33 - <i>Inhalable Dust Results for 3100 Operators</i> .....	159
Table 34 - <i>Sulphuric Acid Mist Results for 3100 Operators</i> .....	160
Table 35 - <i>Inhalable Dust Results for 3200 Operators</i> .....	161
Table 36 - <i>Sulphuric Acid Mist Results for 3200 Operators</i> .....	162
Table 37 - <i>Inhalable Dust Results for 3300 Operators</i> .....	163
Table 38 - <i>Sulphuric Acid Mist Results for 3300 Operators</i> .....	164
Table 39 - <i>Inhalable Dust Results for 3400 / 3510 Operators</i> .....	165
Table 40 - <i>Sulphuric Acid Mist Results for 3400 / 3510 Operators</i> .....	166
Table 41 - <i>Hydrogen Sulphide Results for 3400 / 3510 Operators</i> .....	167
Table 42 - <i>Inhalable Dust Results for 3500 Operators</i> .....	168
Table 43 - <i>Inhalable Dust Results for 3600 Operators</i> .....	169
Table 44 - <i>Inhalable Dust Results for 3700 Operators</i> .....	170
Table 45 - <i>Inhalable Dust Results for 3700 Furnace Operators</i> .....	171
Table 46 - <i>Inhalable Dust Results for Packaging Operators</i> .....	172
Table 47 - <i>Inhalable Dust Results for 3800 Operators</i> .....	173
Table 48 - <i>Inhalable Dust Results for 3900 Operators</i> .....	174
Table 49 - <i>Solvent Results for 3900 Operators</i> .....	175
Table 50 - <i>Inhalable Dust Results for 5900 Operators</i> .....	176
Table 51 - <i>Ammonia Results for 5900 Operators</i> .....	177



## **CHAPTER 1 – INTRODUCTION**

### **Problem Statement**

During 2003, a study was initiated at the Murrin Murrin mine site, located in the West Australian goldfields. Murrin Murrin is operated by Murrin Murrin Operations Pty. Ltd., which in turn is managed by a joint venture between Minara Resources and Glencore International AG.

The research was facilitated by the establishment of a collaborative agreement between Murrin Murrin Operations Pty. Ltd. and Edith Cowan University. The title of the project was “Establishing best practice protocols in the management of occupational and environmental health in a high risk mining and ore processing environment”. Under this agreement, the university has provided support to company employees conducting research.

The Murrin Murrin mine site uses a complicated chemical process to extract nickel and cobalt from ore, and as a result, employees and contractors are exposed to a wide variety of chemical hazards. These hazards had not been fully identified and assessed, which represented a serious knowledge gap in the company’s ability to prevent long-term occupational diseases in its workforce.

### **Aim and Scope**

The aim of this project was to address the existing knowledge gap by implementing a best practice occupational hygiene monitoring program, which accurately quantified the health risks of workers potentially exposed to chemical hazards at the Murrin Murrin Mine Site.

This project was restricted to employees of Murrin Murrin Operations Pty. Ltd. Contractors were not included.

In addition, only those contaminants that are encountered during normal production processes were assessed.

These exclusions were necessary in order to restrict the scale of the project to a manageable size. The process plant at Murrin Murrin is extremely maintenance intensive, and the number of different maintenance tasks would be almost impossible to define, as would the chemicals used to conduct this maintenance. To further complicate this issue, major maintenance tasks are generally concentrated into annual plant shutdowns, and are often conducted by contractors who may only be on site for a few days.

## **Overview of the Study**

Chapter 2 provides the background information required to gain an understanding of the study that was conducted. It commences with a discussion on the legislative framework present in Western Australia that supports the need for a study such as this one. It provides information on exposure standards and basic occupational hygiene principles which are aimed at assisting the readers understanding of the thesis. It then discusses information specific to Murrin Murrin by outlining the entire production process. This chapter concludes with a brief overview of the monitoring that was conducted prior to the commencement of this study, and the problems associated with it.

In Chapter 3 relevant literature is reviewed. The research hypotheses and research methods are discussed and the various options explored in order to justify the selected methods.

Chapter 4 contains the results of the study. It outlines the entire monitoring program and the decisions which were made in developing it, as well as comparing it to the other historical monitoring programs which have been conducted at Murrin Murrin. A statistical summary of the monitoring results is then presented

Chapter 5 then completes the thesis by discussing the meaning of the results, as well as the conclusions which can be drawn.

## CHAPTER 2 – BACKGROUND INFORMATION

### Legislative Overview

The requirement to protect employees from the potentially damaging effects of exposure to atmospheric contaminants is enshrined in Western Australian legislation, thereby providing a legal basis to justify this study.

The safety and health of employees at Murrin Murrin is governed by the Mines Safety and Inspection Act 1994 ("*Mines Safety and Inspection Act*," 1994 (WA)), and its accompanying regulations, the Mines Safety and Inspection Regulations 1995 ("*Mines Safety and Inspection Regulations*," 1995 (WA)). This Act encompasses all activities which fit the definition of a “mining operation” ("*Mines Safety and Inspection Act*," 1994 (WA), s. 4.). Compliance with the Act and Regulations is overseen by the Department of Consumer and Employment Protection (DOCEP).

Under this Act, employers have a general duty of care to “provide and maintain at a mine a working environment in which that employer’s employees are not exposed to hazards” ("*Mines Safety and Inspection Act*," 1994 (WA), s. 9.). This is outlined in Section 9 of the Act, which goes on to state that to fulfil this duty employers must develop safe systems of work, provide adequate information, instruction, training and supervision, actively consult with employees regarding issues of safety and health, provide all necessary personal protective equipment, and to ensure that plant and substances are managed appropriately ("*Mines Safety and Inspection Act*," 1994 (WA), s. 9.).

To assist employers with these obligations, all employees must take “reasonable care to ensure his or her own safety and health at work, and to avoid adversely affecting the safety and health of any other person through any act or omission at work” ("*Mines Safety and Inspection Act*," 1994 (WA), s. 10.) . The Act thus places an obligation on employers and employees to work together to improve workplace health and safety.



At Murrin Murrin, a whole host of atmospheric contaminants exist which have the potential to adversely effect human health. It is these hazards that form the focus of this study.

Contained within the Mines Safety and Inspection Regulations 1995, are several sections which relate directly to atmospheric contaminants. The most important of these in terms of this study are:

- Regulation 9.11 (1) which states that “each responsible person at a mine must ensure that any atmospheric contaminants in workplaces at the mine are maintained at levels below the exposure standard (see Chapter 2 for further information on exposure standards) for the atmospheric contaminant and as low as practicable” (“Mines Safety and Inspection Regulations,” 1995 (WA), r. 9.11 (1).);
- Regulation 9.1 which defines the exposure standards as those “specified in Worksafe Australia’s National Exposure Standards (NOHSC:1003)” (“Mines Safety and Inspection Regulations,” 1995 (WA), r. 9.1.);

The regulatory information supplied above is only a summary, and there are numerous other regulations relating to the control and management of chemical hazards which have not been outlined above. These will be specified throughout the rest of the thesis as necessary.

## **Exposure Standards**

The use of exposure standards to evaluate work environments is an integral part of this study. It is therefore important to review how these standards are derived and utilised.

In Australia, exposure standards are set by the National Occupational Safety and Health Commission (NOHSC) and outlined in a publication entitled “Exposure Standards for Atmospheric Contaminants in the Occupational Environment” (National Occupational Health and Safety Commission, 1995a).

In this publication, an exposure standard is defined as “an airborne concentration of a particular substance in the worker’s breathing zone, exposure to

which, according to current knowledge, should not cause adverse health effects nor cause undue discomfort to nearly all workers” (National Occupational Health and Safety Commission, 1995a, p. 70) .

These standards are determined by a process involving an extensive literature review for each individual atmospheric contaminant. These reviews source information on concentrations which may have led to adverse health effects in both humans and animals. When interpreting these standards throughout this report it is important to remember the following:

- Not all atmospheric contaminants have an exposure standard. This does not mean that they are not hazardous, it may just reflect that little health related information is available (National Occupational Health and Safety Commission, 1995a, p. 6);
- They do not represent a value above which health effects are guaranteed to occur, and below which, there will be no health effects. This is due to variances in the susceptibility of individuals which means that some individuals may suffer health effects at concentrations well below these standards (National Occupational Health and Safety Commission, 1995a, p. 5);
- As previously stated, exposure standards are developed by reviewing the scientific literature regarding the atmospheric contaminant of concern. Typically this literature contains both animal and human dose-response data. Most of the exposure standards used in Australia are sourced from the ACGIH (National Occupational Health and Safety Commission, 1995a) who state that “the amount and quality of the information that is available for each substance varies over time” (American Conference of Governmental Industrial Hygienists, 2005, p. 3). As more information becomes available it is not uncommon for exposure standards to be reduced. The standards from crystalline silica are a recent example of this (National Occupational Health and Safety Commission, 2004);

- Employees may be exposed to more than one contaminant that effects the same organs of the body. This issue is discussed in detail in Chapter 3 as it can have significant repercussions;
- Factors such as extremes of temperature and workloads can also effect an individual's response to an atmospheric contaminant. For example, high workloads can lead to an increased cardiopulmonary demand (American Conference of Governmental Industrial Hygienists, 2005) thereby increasing respiration rates. High temperatures can also increase respiration rates, but due to an increase in sweating, these temperatures can also increase the level of irritation from substances which are soluble in water (Di Corleto, Coles, & Firth, 2003);
- There are three types of standards, namely TWA (Time Weighted Average), STEL (Short Term Exposure Standard) and Peak, which are defined as follows;
  - TWA – “the average airborne concentration of a particular substance when calculated over a normal eight-hour working day, for a five-day working week” (National Occupational Health and Safety Commission, 1995a, p. 70).
  - STEL – “a 15 minute time weighted average exposure which should not be exceeded at any time during a working day even if the eight-hour TWA average is within the TWA exposure standard. Exposures at the STEL should not be longer than 15 minutes and should not be repeated more than four times per day. There should be a least 60minutes between successive exposures at the STEL” (National Occupational Health and Safety Commission, 1995a, p. 70).
  - Peak – “a maximum or peak concentration of a particular substance determined over the shortest analytically practicable period of time which does not exceed 15 minutes” (National Occupational Health and Safety Commission, 1995a, p. 70).

Generally, TWA exposure standards refer to atmospheric contaminants which have the potential to cause long term, chronic health effects, while Peak standards protect against short term, acute effects (eg. irritation). STEL standards are used in conjunction with TWA standards to provide protection against contaminants which have the potential to cause both short and long term effects (National Occupational Health and Safety Commission, 1995a, p. 10).

### **Basic Principles of Exposure Assessment**

Workplace exposures to atmospheric contaminants are generally assessed in accordance with the following basic steps:

1. Identify the atmospheric contaminants in the workplace – this is achieved by studying the production process, speaking to workers, etc.
2. Make a preliminary assessment as to whether each contaminant is likely to cause adverse health effects. This can be achieved by consulting Material Safety Data Sheets (MSDS), speaking to workers, etc.
3. Conduct atmospheric monitoring as required.
4. Analyse and interpret the results.

These basic steps have been acknowledged by the National Occupational Health and Safety Commission, who have recommended the following process when evaluating potential exposures:

1. Decide who will do the assessment;
2. Divide the work into units for assessment;
3. Identify substances in the working environment;
4. Determine which substances are hazardous;
5. Obtain information about hazardous substances;
6. Inspect workplace and evaluate exposure;
7. Evaluate the risk;
8. Identify actions resulting from conclusions about risks;
9. Record the assessment;

10. Review the assessment as required.

(National Occupational Health and Safety Commission, 1994b, p. 4-25)

### **Identification of Atmospheric Contaminants**

In order to identify the atmospheric contaminants that may be present it is first necessary to identify all potential sources, which can include the following as identified by the British Occupational Hygiene Society:

- Raw materials (eg. ores, reagent chemicals).
- Contaminants of raw materials which may be naturally present.
- Ancillary chemicals (eg. catalysts, reaction solvents, etc)
- Intermediate products
- End products and their impurities
- By-products
- Waste products
- Formulated products
- Part of the workplace (eg. insulation)
- By products from support processes (eg. welding)

(Guest, Cherrie, Gardner, & Money, 1993, p. 20-21)

In order to ensure that all potential sources are identified it is necessary to involve all levels of the organisation, particularly the individuals who actually do the work (i.e. production operators, supervisors, etc).

Creating this listing of potential contaminants has the additional benefit of enabling the site to comply with Regulation 7.25 of the Mines Safety and Inspection Regulations 1995 which states that each site must maintain a register of hazardous substances ("Mines Safety and Inspection Regulations," 1995 (WA), r. 7.25 (1).).

NOTE – Hazardous substance means a substance which:

- a. is listed on the National Occupational Health and Safety Commission's *List of Designated Hazardous Substances* [NOHSC:1005 (1994)] or
- b. has been classified as a hazardous substance by the manufacturer or importer in accordance with the National Occupational Health and Safety Commission's *Approved Criteria for Classifying Hazardous Substances* [NOHSC:1008 (1994)].

(National Occupational Health and Safety Commission, 1994a, p. 7)

### **Preliminary Assessment**

Having identified all potential sources of atmospheric contaminants, it is then necessary to gather information on each of them. This information can be obtained from MSDS's, government publications, technical references, interviewing workers, etc.

Once the required information is obtained, it is then necessary to identify those requiring atmospheric monitoring. From professional experience, this is generally done by addressing the following questions:

- Physical properties – Does it generate a dust or mist which can be inhaled?
- Toxicity – Is the material likely to create adverse health effects in exposed individuals? Is it hazardous via inhalation?
- Exposure potential – Are workers likely to be exposed to it (i.e. is there anyone working with or near the material, how much of the material is present, can the material escape from packaging or process vessels, etc)?
- Does it have an exposure standard that needs to be complied with?
- Existing controls – Are there controls in place that prevent or reduce exposure, and how effective are they?

### **Conduct Atmospheric Monitoring**

Having considered each potential source according to the above criteria, it is then possible to implement an atmospheric monitoring program. The aim of such a

program is to collect sufficient data to enable the company to decide whether or not the material is likely to cause adverse health effects to exposed individuals.

This data is collected by conducting monitoring that is representative of what the individual is actually breathing. This is known as personal sampling, and involves sampling air from within the breathing zone of the worker, which is defined as “a hemisphere of 300mm radius extending in front of their face and measured from the midpoint of an imaginary line joining the ears” (National Occupational Health and Safety Commission, 1995a, p. 57).

For most atmospheric contaminants there are well defined methods to conduct personal monitoring. These methods are discussed in more detail in this Chapter 3.

In addition to selecting a monitoring method, it is also necessary to answer the following questions when developing a sampling program:

- How many samples are required?
- When should the samples be taken?
- How long should each sample run for?
- Who should be monitored?
- How accurate do the results need to be?

These questions, and the theories behind their answers, will be explored more thoroughly later in the thesis when the actual monitoring program is developed.

### **Analysis and Interpretation of Results**

The results of the monitoring program are compared to the appropriate exposure standard to determine the risks of workers suffering adverse health effects. To assist with this, complex statistical methods have been developed, which will be outlined later in the thesis.

## **Production Process**

In order to place the size and complexity of this study in context, it is necessary to briefly outline the production process used at Murrin Murrin. As will be shown, the process depends upon the use of a wide variety of chemicals to extract the nickel and cobalt. Each of these chemicals has the potential to cause adverse health effects if employees are exposed to sufficient atmospheric concentrations.

Figure 1 below, shows a flow chart of the Murrin Murrin process.



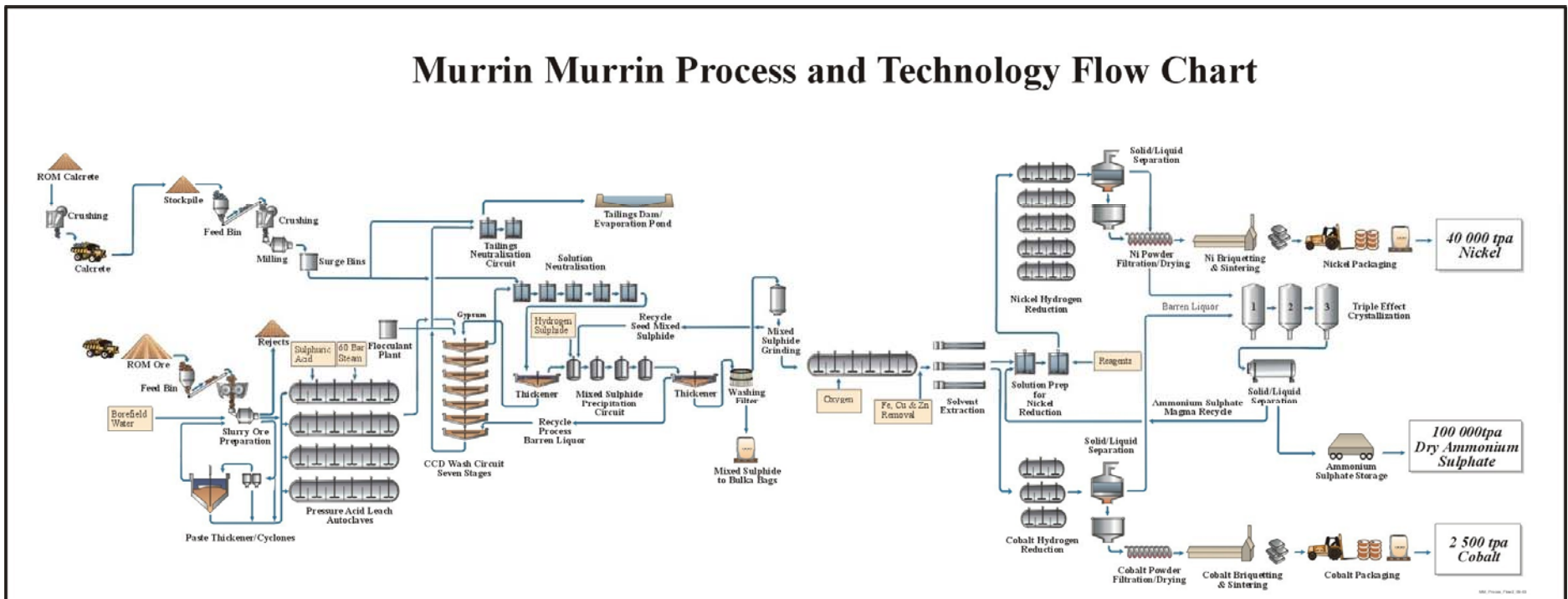


Figure 1. Murrin Murrin Production Process (Minara Resources, 2005).

The process at Murrin Murrin commences with the mining of ore in several open cut pits. The ore from these pits is transferred to the ROM (Run of Mine) Pad where it is stored in large piles (known as fingers) according to its nickel and cobalt content. Ore is then taken from these “fingers” and fed into the processing plant.

The processing plant consists of three main sections - Utilities, Ore Leach and Refinery.

Utilities is responsible for generating electrical power via both steam and gas turbines, as well as producing potable and demineralised water, hydrogen sulphide gas, sulphuric acid, oxygen, nitrogen and hydrogen for use in the plant.

Ore Leach receives the ore from the mining ROM Pad. The ore is initially screened to remove large rocks and objects before it goes through a mill where it is crushed to obtain a consistent particle size (see “Slurry Ore Preparation” in Figure 1). Water is also added to produce slurry. From the mill, the slurry is fed into autoclaves (see “Pressure Acid Leach Autoclaves” in Figure 1) that contain sulphuric acid and operate at approximately 250°C and 40 atmosphere pressure. The purpose of these autoclaves is to extract the metals from the ore and into solution.

After passing through the autoclaves, the slurry is fed through a series of large settling tanks known as CCD’s (Counter-Current Decantation) (see “CCD Wash Circuit” in Figure 1). The purpose of the CCD’s is to separate the solution from the solids, which are pumped out to the tailings dam as waste. At this stage of the process, the solution has a high pH which is reduced via the addition of calcrete. This is known as neutralisation (see “Solution Neutralisation” in Figure 1). Following neutralisation, the solution moves forward into the Refinery after the addition of hydrogen sulphide gas.

NOTE – calcrete is mined at a nearby pit and crushed on site by a contract company. It is then mixed with water to produce slurry and pumped into the plant as required.

The purpose of the Refinery is to separate the nickel and cobalt from the other metals present in solution, and to produce high purity nickel and cobalt briquettes. This is achieved via the addition of hydrogen sulphide gas, which

precipitates the metals out of solution in the form of metal sulphides. These sulphides are then put through an autoclave in the presence of oxygen to produce soluble metal sulphates and to remove iron and copper from the solution. Following this the solution is pumped into the solvent extraction section where the nickel and cobalt are separated into two separate streams. Iron and zinc are also stripped from both streams (see “Solvent Extraction” in Figure 1). The nickel and cobalt streams then pass into separate autoclaves that contain hydrogen and ammonia (see “Nickel Hydrogen Reduction” and “Cobalt Hydrogen Reduction” in Figure 1). These autoclaves reduce the cobalt and nickel into metal powders, which then go through pug mills and a sintering furnace to produce briquettes.

Ammonium sulphate is produced as a by-product of the process.

### Historical Data

Prior to the commencement of this study, monitoring programs for atmospheric contaminants were primarily based upon the state government’s contaminant monitoring system (CONTAM).

CONTAM is a system administered by the DOCEP. Under this system Minara Resources is required to conduct monitoring on specific occupations for specific contaminants. This is known as the CONTAM quota which is shown below:

Table 1

*CONTAM Quota for Murrin Murrin*

Job Classification	Contaminant	Number of Samples
Mining – Charge and Blast	Respirable dust and silica	2
Mining – Excavation and Ore Transport	Respirable dust and silica	6
Process Plant Operators	Inhalable Dust	4
	Respirable Dust	1
Laboratory – Sample Preparation Operators	Respirable dust and silica	2

(Department of Industry and Resources, 2003)

The results of this monitoring are then reported back to the DOCEP. The major deficiency of this system is that it is designed to meet the needs of the government, and is not representative of the risks present on site.

In addition to the CONTAM sampling requirements, monitoring had also been conducted in various areas in response to employee concerns. Two major problems associated with this system were that the monitoring programs became reactionary, and they were targeted towards perceived risk as opposed to actual risk.

The above monitoring however has identified the major atmospheric contaminants which workers are exposed to. These contaminants and their potential health effects are discussed below.

## **Potential Health Effects**

### **Nickel Dusts**

Nickel was the subject of a major study conducted by Minara Resources (Wing & Cross, 2003). This study involved the implementation of a comprehensive sampling program conducted in accordance with the methods outlined later in this thesis.

The final report provided a baseline of exposure for all of the operator types within the refinery area of the processing plant. The areas in which high exposures were identified have now been targeted for engineering controls, and immediate precautions have been taken to protect employees (i.e. respiratory protection).

Nickel was targeted as it is currently the subject of a European Union risk assessment co-ordinated by the Danish government. It is expected that the results of this assessment will lead to a lowering of exposure standards.

Nickel can be divided into four main classes – metallic (elemental and alloyed), oxidic (including hydroxides, carbonates, complex Ni-Cu oxides, forms of nickel oxide, etc), sulphidic (including the subsulphide), and soluble (including sulphate, chloride, etc).

The major health effects associated with nickel compounds are respiratory cancers (i.e. lung and nasal-sinus) as a result of exposure via inhalation, and

dermatitis due to dermal exposure (Nickel Producers Environmental Research Association, 1997, p. 7).

This issue regarding nickel exposure is complicated further by the fact that carcinogenicity classifications differ from country to country and according to the type of nickel. However, at present, the following is generally agreed upon:

- Metallic Nickel – not suspected of being a carcinogen (American Conference of Governmental Industrial Hygienists, 2005, p. 42).
- Oxidic Nickel – respiratory cancer has been linked to less soluble forms (such as oxidic nickel) where exposures have exceeded 10mg Ni/m<sup>3</sup> (Nickel Producers Environmental Research Association, 1997, p. 8).
- Sulphidic Nickel – these include nickel sulphide and nickel subsulphide. Both of these compounds are insoluble and are generally classified as known human carcinogens (Nickel Producers Environmental Research Association, 1997, p. 8).
- Soluble Nickel – these compounds are generally suspected of promoting cancer, rather than initiating it (Nickel Producers Environmental Research Association, 1997, p. 9). However, recent evidence suggests “that the role of soluble nickel may be more important than currently recognised” (Grimsrud, Berge, Haldorson, & Anderson, 2002, p. 1131).

The International Agency for Research on Cancer (IARC) classifies “Nickel Compounds” as a Group 1 (Carcinogenic to humans) carcinogen (International Agency for Research on Cancer, 2004).

Murrin Murrin is known to generate metallic, soluble and sulphidic forms of nickel during the refining process.

### **Cobalt Dusts**

Cobalt was included as an appendix in the above mentioned report relating to nickel (Wing & Cross, 2003). The monitoring program and statistical analysis were conducted in the same manner as for nickel.

The results showed that certain operator groups were being exposed to concentrations of cobalt exceeding the exposure standard. These areas were also

targeted for engineering controls and immediate measures were taken to protect employees (i.e. respiratory protection).

Exposure to cobalt in its various forms has been linked to asthma, pulmonary function changes and myocardial effects. In terms of carcinogenicity, the American Conference of Governmental Industrial Hygienists (ACGIH) class it as A3 - Confirmed animal carcinogen with unknown relevance to humans (American Conference of Governmental Industrial Hygienists, 2005, p. 21), while IARC classify it as 2B – Possibly carcinogenic to humans (International Agency for Research on Cancer, 2004).

### **Sulphuric Acid Mist**

Sulphuric acid is manufactured on site, and is used to leach the nickel and cobalt from the ore.

The health effects of sulphuric acid are related to its corrosiveness. Exposure to sufficient concentrations will cause irritating effects on the skin, eyes, and the respiratory and gastrointestinal tracts. Exposure to high concentrations will cause chemical burns on exposed areas of the body (Agency for Toxic Substances and Disease Registry, 1998).

The specific health effects relating to the inhalation of sulphuric acid mists are “mucous membrane irritation, coughing, bronchitis, ulceration, bloody nose, lung tissue damage, chemical pneumonitis, pulmonary oedema and death”(Risk Management Technologies, 2003).

Sulphuric acid mists have been classified as a Group 1 (Carcinogenic to humans) carcinogen by IARC (International Agency for Research on Cancer, 2004), and as an A2 carcinogen (Suspected human carcinogen) by the ACGIH (American Conference of Governmental Industrial Hygienists, 2005, p. 52).

Insufficient monitoring has been conducted to adequately determine the risks posed to employee health by their exposure to sulphuric acid mist.

### **Hydrogen Sulphide**

Hydrogen sulphide is manufactured on site and is used to produce cobalt and nickel sulphides. It is a very pungent gas and can be detected at extremely low

concentrations. Its acute health effects are well documented. At low concentrations it irritates the eyes and can lead to conjunctivitis, while at higher concentrations the ability to smell it is lost, and as the concentration increases it can lead to pulmonary oedema, cessation of breathing and death (National Institute for Working Life - The Nordic Expert Group for Criteria Documentation of Health Risks from Chemicals and The Dutch Expert Committee on Occupational Standards, 2001).

“Chronic health effects caused by repeated exposures to hydrogen sulphide have not been established. Signs and symptoms (eg. Headaches, fatigue, dizziness, irritability, and loss of libido) attributed to chronic, low level exposures could result from long-term, low-level exposures to hydrogen sulphide but could also occur from damage inflicted by isolated, or repeated, unmeasured high-level exposures in healthy persons or those suffering from existing neurologic disease”(American Conference of Governmental Industrial Hygienists, 2002).

Everybody working at Murrin Murrin is required to carry a personal gas detector and respirator at all times ("Anaconda Operations Murrin Murrin - General Safety and Environment Induction Handbook," 2001). This detector alerts the wearer to hydrogen sulphide concentrations exceeding 10ppm. When this occurs, the wearer is required to don their respirator and evacuate the area. In this way, individuals are protected from acute health effects arising from high exposures (i.e. if a valve or tank leaks).

Insufficient monitoring has been conducted to adequately determine the risks posed to employee health by constant low level exposure to hydrogen sulphide.

## **Sulphur Dioxide**

Sulphur dioxide is an intermediary product in the formation of sulphuric acid and exhibits both acute and chronic health effects.

Acute health effects include irritation of the eyes and upper respiratory tract, narrowing of the airways, runny nose, choking and coughing. As the concentration increases these symptoms become intolerable and the individual is forced to leave the area (National Institute of Occupational Safety and Health, 2001).

Chronic exposure to sulphur dioxide can lead to permanent pulmonary impairment (National Institute of Occupational Safety and Health, 2001, p. 1).

Individuals are currently protected by the use of respiratory protection during high exposure activities. Insufficient monitoring has been conducted to adequately determine the risks posed to employee health by continuous exposure to low levels of sulphur dioxide.

### **Ammonia**

Ammonia is trucked to site and used in the production process.

The main health effects of ammonia are irritation of the respiratory tract and eyes (American Conference of Governmental Industrial Hygienists, 2001).

Insufficient monitoring has been conducted to adequately determine the risks posed to employee health by continuous low level exposure to ammonia.



## **CHAPTER 3 – RESEARCH DESIGN**

As was highlighted in the previous background chapters, the processing plant at Murrin Murrin is extremely complex, whilst the atmospheric monitoring programs have been comparatively basic. As a result, it was hypothesised that:

1. Chemical hazards at Murrin Murrin had not been adequately identified; and
2. The occupational hygiene monitoring protocols did not adequately quantify worker exposures to these chemical hazards; and
3. The implementation of a comprehensive hazard identification and monitoring program, would greatly improve capacity to quantify health risks of exposed workers.

In order to test the validity of these statements, it was necessary to follow the basic occupational hygiene principles outlined earlier. This chapter will expand on this information and discuss the various alternatives available. It will then outline the research design that was selected and the reasons why.

### **Hypothesis 1 - Chemical Hazards at Murrin Murrin Had Not Been Adequately Identified**

As outlined earlier, it is a regulatory requirement for a site to produce a register of all hazardous substances present on site. The development of such a register was crucial to this research because the substances it identified formed the basis of the atmospheric contaminants focussed on.

It was therefore necessary to decide upon the best way of developing a hazardous substance register.

Due to the complexity of the site, and the large number of chemicals in use, it was obvious from the start that assistance would be required from all levels of the organisation, i.e. Operators, Supervisors and Managers.

This strategy is in line with the National Occupational Health and Safety Commission (NOHSC) who state that:

A sound knowledge of the work is essential for doing an adequate assessment. Therefore, even if an outside consultant is engaged to help with the assessment, workplace personnel who have a thorough knowledge of the work should always be involved. (National Occupational Health and Safety Commission, 1994b, p. 4)

Having established that a team based approach was required the processing plant was split up according to the three main management areas, namely Utilities, Ore Leach and Refinery. Both formal and informal meetings were held with either individuals or teams of individuals from within each area (within each of these areas, the process plant is divided into several smaller sections. Individuals from each of these smaller sections were involved). During these meetings, specific information on each of the chemicals present in each area was collected. This information was entered into two spreadsheets that included the following details for each chemical:

- Name
- Manufacturer
- MSDS availability (i.e. did we have one?)
- Dangerous Goods classification (if any)
- Hazardous Substance classification (either is or is not)
- Use
- Location (i.e. area of the plant where it is used)
- Amount stored
- Who is exposed
- How exposure could occur (i.e. specific tasks or events were identified)
- Route of exposure (i.e. is the chemical hazardous via inhalation, skin absorption, etc. This was determined by consulting the relevant MSDS)
- Frequency of exposure
- Exposure controls

The spreadsheets used were based upon templates produced by the NOHSC (National Occupational Health and Safety Commission, 1994b).

**Hypothesis 2 - The occupational hygiene monitoring protocols did not adequately quantify worker exposures to these chemical hazards**

From the information gathered in the hazard identification process outlined above, it was possible to decide upon the chemicals that required atmospheric monitoring.

This hypothesis was then tested by comparing these requirements with the historical sampling programs that had been conducted.

**Hypothesis 3 - The implementation of a comprehensive hazard identification and monitoring program, will greatly improve capacity to quantify health risks of exposed workers.**

In order to test this hypothesis, an appropriate monitoring program was developed.

The basis for the sampling program was the hazard identification work outlined above. This work ensured that the workplace exposures requiring further evaluation were identified.

In designing the sampling program, the following was considered;

- Health effects of the contaminants of interest;
- How to conduct the monitoring;
- How long to sample for;
- Who to sample;
- When to sample;
- How many samples to take;
- How often to repeat monitoring into the future.

A significant amount of research relating to atmospheric contaminant sampling programs has been conducted, and several of the major occupational hygiene related professional institutes have produced documents on this subject. These documents are as follows:

- The National Institute of Occupational Safety and Health (NIOSH) produced a publication entitled “Occupational Exposure Sampling Strategy Manual” (Leidel N.A., Busch, & Lynch, 1977);
- The British Occupational Hygiene Society (BOHS) produced a publication entitled “Technical Guide 11 – Sampling Strategies for Airborne Contaminants in the Workplace” (Guest et al., 1993);
- The European Committee for Standardization (CEN) produced a publication entitled “Workplace Atmospheres – Guidance for the assessment of exposure by inhalation to chemical agents for comparison with limit values and measurement strategy” (European Committee for Standardization, 1995);
- The American Industrial Hygiene Association (AIHA) produced a publication entitled “A Strategy for Assessing and Managing Occupational Exposures” (Mulhausen & Damiano, 1998);
- The Australian Institute of Occupational Hygienists (AIOH) produced a document entitled “Simplified Monitoring Strategies” (Grantham, 2001).

The NIOSH document was produced in 1977 and is the earliest of the above publications. The aim of the sampling program it recommends is to identify and monitor the “maximum risk employee”, or the “employee believed to have the greatest exposure” (Leidel, Busch, & Lynch, 1977, p. 33).

If possible, this individual is selected by observing the workplace and taking into account factors such as the distance workers are from the source of the atmospheric contaminant, (i.e. the closer they are, the higher the exposure is assumed to be), worker mobility (i.e. how long does the worker spend near the source of the atmospheric contaminant), air movement patterns (i.e. workers downwind of ventilation systems may have higher exposures) and individual work practices.

Due to the large number of variables which can affect individual exposures, identifying the “maximum risk employee” has the potential to be extremely difficult,

especially if there are a large number of workers. In such cases, the strategy requires that workers be segregated into groups who would be expected to have similar exposures. A statistically derived number of individuals from this group are then selected randomly and sampled. The number of samples required is outlined in Table 2 below.

Table 2

*Number of Samples Required to Ensure a 90% Probability of Sampling an Individual with an Exposure in the Highest 10% of all Exposures*

<b>Size of worker group</b>	<b>Number of samples required</b>
8	7
9	8
10	9
11-12	10
13-14	11
15-17	12
18-20	13
21-24	14
25-29	15
30-37	16
38-49	17
50	18

*Note*, for numbers less than 8, all workers must be sampled  
(Leidel et al., 1977, p.35)

As can be seen, the ratio of samples to worker numbers decreases as the number of workers increases.

If any workers were subsequently found to have exposures in excess of the action level (defined as 50% of the exposure standard), then the employer would be required to:

1. “Identify all employees who may be exposed at or above the action level; and
2. Measure the exposure of the employees so identified” (Leidel et al., 1977, p. 37).

This strategy is what is known today as compliance monitoring because the aim of it is to prove to regulatory authorities that no worker could be exposed to concentrations above the exposure standard. As stated in the document the theory is that:

If the exposure of the most exposed employee, regardless of how he is identified, is below the action level, then it is reasonable to assume that measurements of exposure of the other employees in that operation would be below the action level. (Leidel et al., 1977, p. 37)

No further action would be required unless the maximum risk measurement was above the action limit, or if the workplace conditions changed.

If a worker was exposed to a concentration exceeding the action level then re-sampling would be required every two months, and monthly sampling would be required of workers whose exposure exceeded an exposure standard. This pattern would continue until two consecutive samples taken at least one week apart recorded exposures less than the action level (i.e. after the employer has taken action to reduce exposures).

By concentrating on the “maximum risk worker”, this strategy reduces the number of samples required to prove compliance with exposure standards to an absolute minimum. It is therefore a relatively low cost option which would be attractive to smaller employers with minimal resources (i.e. those that do not employ an occupational hygienist).

However, such compliance based strategies have several deficiencies.

Rappaport points out that if the air concentration was constant, then the conclusions generated from compliance based programs would be reasonable (Rappaport, 1991). However “exposures vary to such an extent that a person found to be exposed at, say, half of the exposure standard on one day might be exposed at twice the standard on the next” (Rappaport, 1991, p. 67). Thus the conclusions generated from compliance based sampling will be dependant upon the time during which the sample is taken (the results could be low or they could be high), and

obtaining an accurate picture of the exposure situation will be dependant upon taking sufficient samples to accurately assess the situation. As stated by Rappaport, “a sampling strategy which defines exposure assessment as an inherently statistical problem should be employed” (Rappaport, 1991, p. 67).

Unfortunately, an interesting side effect of taking additional samples is that it increases the likelihood of finding an exposure standard exceedance (Tornero-Velez, Symanski, Kromhout, Yu, & Rappaport, 1997). This means that a worker or group of workers exposures could either be classified as compliant (below the exposure standard) or non-compliant (above the exposure standard) depending upon how many samples were taken. Obviously, this provides employers with a disincentive to implement rigorous sampling programs.

NIOSH recognised this problem with variability and stated that “the employer should attempt to limit the probability of employee overexposure (daily exposures exceeding the exposure standard) to 5%” (Leidel et al., 1977, p. 67). As such, their recommended sampling strategy was compliance based, and this compliance was judged on the basis of the percentage overexposure.

Another significant problem with compliance based monitoring is that it does not give a picture of the overall or actual risk that atmospheric contaminants pose to the workforce as a whole. By concentrating on the maximum risk employee, it gives a biased view.

This biased view means that the results are not as useful for epidemiological research. In order to determine the dose/response mechanism of a chemical, researchers require an accurate estimate of the workers average exposure (Gardiner, 1995). This point is of critical importance. Collecting data in a manner that is epidemiologically significant will enable research to be conducted that will result in the establishment of improved exposure standards.

This concentration on the mean or average exposure leads to another significant point – what parameter provides the best measure of health risk?

For long term, chronic health risks such as cancer and pneumoconiosis, the general consensus is that the average or mean exposure is the ideal measure of risk.

Studies relating mean exposures to potential health effects were being conducted as far back as the 1930’s and 40’s. A useful article on these studies was

produced by Roach (Roach, 1953). Pneumoconiosis is a long term disease of the lungs, and in this article Roach discusses its exposure/response curve. This curve plots total long term dust exposure against the probability of developing the disease. He is therefore relating the risk of disease to the workers long term average dust exposure.

This theory of using mean exposures as a measure of long term health risk has also been proposed to describe the biological processes which lead to disease. Rappaport discussed a model which relates exposure to overall dose, tissue damage and the risk of disease (Rappaport, 1991). The complexities of this model will not be discussed; however the main points are that when an individual is exposed to a chemical, a certain proportion is absorbed into the body. This absorption leads to a series of burdens throughout the body which will then be reduced by the body's elimination mechanisms. The level of burden that balances out in the body can be related to tissue damage, which is offset by the body's ability to repair itself. These mechanisms that the body uses to eliminate chemicals and to repair the damage they cause, leads to a damping of the exposure variability. Thus the large variations of atmospheric contaminants that an individual may be exposed to are not necessarily translated to concentrations within the body. This means that for long term health effects, short term peak exposures are not important, and the argument questions the effectiveness of compliance and exceedance based sampling strategies.

The mechanism outlined above assumes linear kinetics (i.e. increasing concentrations leads to a proportional increase in health risks). Non linear kinetics can arise from:

changes in individual uptake or susceptibility with time, from synergistic or antagonistic effects related to concurrent exposures to other chemical or biological agents, from allergenic responses to sensitising agents, or from an upward curving relationship between burden and damage associated with episodes of intense exposure. (Rappaport, 1991, p. 86)

The last point is the most significant from a sampling perspective. For acute toxins in which an elevated exposure can cause an immediate health effect, the exposure peaks are of more significance than the long term average exposure.

As can be seen, knowledge of the health effects is critical in designing a sampling strategy. For long term health effects, the strategy needs to accurately define average exposure, while short term effects require a strategy which identifies



and quantifies peak exposures. Indeed, for peak exposures, it is good practice to take action immediately to reduce exposures rather than waiting on the results of a sampling program (Rappaport, 1991).

The theory that long term health effects should be assessed by comparing the mean exposure to the exposure standard is not without its critics. Hewett has pointed out that comparing average exposures to the exposure standard permits some daily exposures to exceed this standard (Hewett, 2001). This therefore, reduces the protection afforded to workers. This argument comes down to the definition of what an exposure standard is. Hewett believes that the exposure standards issued by the standard setting bodies in America (the ACGIH, AIHA, OSHA and NIOSH) “were and are defined as concentrations, averaged across each single shift, that should not be exceeded” (Hewett, 2001, p. 252).

In Australia, TWA exposure standards are set by NOHSC (National Occupational Health and Safety Commission, 1995a). In this publication, two definitions of the TWA exposure standard for contaminants suspected of causing long term health effects are given:

1. “Exposure standards apply to long term exposure to a substance over an eight-hour day, for a five day working week, over an entire working life” (National Occupational Health and Safety Commission, 1995a, p. 5); and
2. “the average airborne concentration of a particular substance when calculated over a normal eight-hour working day, for a five day working week” (National Occupational Health and Safety Commission, 1995a, p. 70).

Clearly, NOHSC is indicating that some averaging is permitted.

In practice however, it is not so simple. The Mines Safety and Inspection Regulations 1995 state that “each responsible person at a mine must ensure that any atmospheric contaminants in workplaces at the mine are maintained at levels below the exposure standard for the atmospheric contaminant and as low as practicable” (“Mines Safety and Inspection Regulations,” 1995 (WA), r. 9.11 (1).). This implies that exposures must never exceed the standard.

Grantham, in his publication for the AIOH, states that the standards must refer to average values due to the large variability of workplace exposures (Grantham, 2001). He then goes on to say that “if a single measurement were the yardstick, nearly every workplace would be out of compliance at some time” (Grantham, 2001, p. 7).

After due consideration of the aforementioned arguments, the following monitoring strategy was decided upon for this study:

1. For long term health effects, concentrate on the mean exposure as a measure of health risk;
2. For compliance reasons, place a limit on the number of samples which exceed the exposure standard.
3. For substances exhibiting short term health effects, it is not appropriate to concentrate on the mean. Details on this are outlined below under the heading of “Monitoring Programs to Assess Risk of Short Term Health Effects”.

It is worth noting that the two parameters outlined above are mathematically linked. That is, by reducing mean exposures, the proportion of samples exceeding the standard will be reduced.

Having decided on the approach, the next questions to be answered were who to sample, when to sample, and how many samples to take.

### **Who, When and How Many?**

The first part of this process is to divide the workers into groups expected to have similar exposures. Such groupings are commonly known as similar exposure groups (SEG's). Each of the main sampling publications outlined above recommends this process as follows:

1. The CEN states “the preferred approach is to subdivide the exposed population into homogenous groups with respect to exposure”(European Committee for Standardization, 1995, p. 9);
2. The AIHA devotes a whole chapter to the establishment of SEGs (Mulhausen & Damiano, 1998, p. 41-56);

3. The BOHS states that the “sampling of every employee with potential exposures to a particular contaminant is not usually a viable proposition” (Guest et al., 1993, p. 43), and then goes onto explaining how to set up SEGs;
4. The AIOH states that for larger work groups, individuals should be grouped either prospectively (before sampling) or retrospectively (Grantham, 2001).
5. As discussed previously, the NIOSH document uses worker groupings (Leidel N.A. et al., 1977).

Establishing the groups prospectively is the most common approach, and was used in this study. It utilises observation and can group workers on the basis of any of the factors outlined below:

- Classifying by process and environmental agent;
- Classifying by process, job, and environmental agent;
- Classifying by process, job, task, and environmental agent;
- Classifying by process, task and environmental agent;
- Classifying work teams; and
- Classifying non-repetitive work

(Mulhausen & Damiano, 1998, p. 42-52)

The BOHS state that having identified the chemicals to be monitored:

Employees are then allocated to exposure zones based on the following criteria:

- a. Similarity of tasks not necessarily exactly the same job)
- b. Exposure to the same range of airborne contaminants (including by-products and intermediates)
- c. Similarity of environment, i.e. process equipment, exposure sources and ventilation arrangements
- d. Identifiability

(Guest et al., 1993, p. 43).

Retrospective grouping involves conducting the monitoring, analysing the results and then making the appropriate groupings. The problem with this strategy is

that it requires a large number of samples to be taken, and is therefore extremely resource intensive. It can cause data to be generated in areas where exposures are under control (Guest et al., 1993, p. 44), and may even cause the collection of data in areas that are obviously either acceptable or unacceptable (Mulhausen & Damiano, 1998, p. 53).

The extra sampling requirements were the main reason why this method was not used. The other reasons were as follows:

1. Results needed to be communicated to the workforce as soon as practicable, therefore the number of required samples had to be the minimum necessary;
2. Workers get tired of wearing the sampling gear as it is uncomfortable, heavy and restricts their movement. Again, this meant that the number of samples needed to be reduced, and those sampled needed to be well targeted;
3. A student from ECU was employed to assist with the monitoring for a period of three months. Therefore, sample numbers had to be controlled to meet this time constraint;
4. Based upon the sampling results, it is possible to regroup workers retrospectively if necessary.

When to sample was a relatively easy decision to make. The literature is unanimous, in that to determine mean exposure levels, it is necessary to implement random sampling. That is, the workers are selected randomly, as are the shift during which they are sampled. The idea is that both the high exposure and the low exposure days are monitored, and by doing so, sampling biases are removed. To ensure that all samples were selected randomly, a computer program incorporating a random number generator was used to develop the sampling program. The process involved assigning numbers to each SEG - atmospheric contaminant combination and each possible working shift, and then using the random number generator to build up the sampling program.

How many samples to take was another decision to be made. Some “rules of thumb” exist, but most methods rely on some sort of statistical analysis of the results.

Examples of these “rules of thumb” have been put forward by the UK Health and Safety Executive which recommends to sample at least one in every 10 workers

in the group (cited in Guest et al., 1993, p. 46) and by Corn who recommends to take at least 3 samples before any statement on the results is made, and that additional samples be taken if the results exceed a 25% spread (cited in Guest et al., 1993, p. 46)

The AIHA state that a “review of statistical theory reveals that there is a point of diminishing returns” (Mulhausen & Damiano, 1998, p. 106) and that:

a plateau is reached in estimating the mean and standard deviation after about six to 10 measurements. Fewer than six measurements leave a great deal of uncertainty about the exposure profile. More than 10 measurements provide additional refinement in estimates, but the marginal improvement may be small considering that cost per measurement is essentially constant. (Mulhausen & Damiano, 1998, p. 106)

The CEN recommend a minimum of six samples per SEG (European Committee for Standardization, 1995, p. 22).

For the reasons outlined above, six samples per worker group, per contaminant were taken. A subsequent analysis of the results would then determine whether additional monitoring was required.

When comparing mean exposures to the exposure standards, it is possible to calculate the required number of samples to achieve a desired level of statistical confidence. This is outlined in Table 3 below.

Table 3

*The Required Number of Samples to Test Compliance with an Exposure Standard at a 95% Significance Level and 90% Power*

Mean/exposure standard	Sample Size				
	Geometric standard deviation	Geometric standard deviation	Geometric standard deviation	Geometric standard deviation	Geometric standard deviation
	= 1.5	= 2.0	= 2.5	= 3.0	= 3.5
0.10	2	6	13	21	30
0.25	3	10	19	30	43
0.50	7	21	41	67	96
0.75	25	82	164	266	384
1.25	25	82	164	266	384
1.50	7	21	41	67	96
2.00	2	6	11	17	24
3.00	1	2	3	5	6

(Rappaport & Selvin, 1987, p. 377)

This table shows that the number of samples required depends upon how close the mean is to the exposure standard, and on the geometric standard deviation (variability) of the results. As can be seen, the number of samples required can become enormous. In fact, the numbers can become so large as to make these methods non-viable.

### **How to Conduct the Monitoring**

The methods to sample atmospheric contaminants are outlined in the Mines Safety and Inspection Regulations 1995 ("Mines Safety and Inspection Regulations," 1995 (WA), r. 9.13 (1).).

The monitoring conducted in this study was carried out in accordance with this regulation as follows:

- Respirable Dust: AS 2985-1987 – Workplace Atmospheres – Method for sampling and gravimetric determination of respirable dust ("AS 2985 - 1987 Workplace Atmospheres - Method for Sampling and Gravimetric Determination of Respirable Dust," 1987);

NOTE – this standard was updated in 2004. This update involved an adjustment in the sampling flow rates required. These changes did not come into effect in the West Australian mining industry until the 1<sup>st</sup> July 2004, and so as a result, the sampling outlined in this study was conducted in accordance with the now superseded standard.

- Inhalable Dust: AS 3640-2004 – Workplace Atmospheres – Method for sampling and gravimetric determination of inhalable dust ("AS 3640 - 2004 Workplace Atmospheres - Method for Sampling and Gravimetric Determination of Inhalable Dust," 2004);

NOTE - this standard was also updated in 2004, however none of the amendments are significant to this study.

- Organic Vapours: AS 2986.1 – 2003 – Workplace Air Quality –Sampling and analysis of volatile organic compounds by solvent desorption/gas chromatography, Part 1: Pumped sampling method ("AS 2986.1 - 2003 Workplace air quality - Sampling and analysis of volatile organic compounds by solvent desorption/gas chromatography, Part 1: Pumped Sample Method," 2003).

The methods outlined above collect a generic sample which can then be forwarded for laboratory analysis to identify specific constituents. During this study, this was done for most of the samples collected (eg. further analysis of inhalable dust samples for metals such as nickel and cobalt). To ensure the accuracy of this analysis, a NATA (National Association of Testing Authorities) certified laboratory was used at all times.

Monitoring for sulphuric acid mist was conducted according to ASTM D 4856 – 99 Standard Test Method for the Determination of Sulfuric Acid Mist in the Workplace Atmosphere (American Society for Testing and Materials, 1999).

Ideally, this monitoring would have been conducted according to the requirements of AS3640 (Murdoch, Foster, & Geyer, 2002), however, it was found that this was not

possible due to an incompatibility between the required collection filter and the sampling pumps (i.e. the sampling pumps were not capable of drawing air through the filters). After seeking advice from the laboratory involved in the analysis of these samples, the above sampling method was selected and the flow rate was increased from one to two litres per minute.

Sampling for hydrogen sulphide, sulphur dioxide and ammonia was conducted using direct reading gas detectors with data-logging capability (i.e. the results over time were recorded and downloaded onto a computer)

### **Statistical Evaluation of Results**

The aim of this sampling program was to quantify worker exposure using a small subset of results, i.e. without sampling every individual during every shift. To do this, it is necessary to define the distribution of exposures.

As discussed, occupational exposures can vary greatly from day to day and shift to shift. This is due to a number of variables which were discussed earlier. The combination of these variables are multiplicative in effect, and as a result, it is believed that most exposure data can be described by a lognormal distribution (Rappaport & Selvin, 1987, p. 374). There are a number of methods of determining the distribution such as probability plotting, however for simplicity, the statistical package supplied by the AIHA entitled IHSTAT (Mulhausen & Damiano, 1998) was used.

This package classifies the distribution as either lognormal or normal and calculates all of the necessary statistics such as:

1. Arithmetic Mean – as discussed this is the best estimate of health risk associated with long term chronic disease. The arithmetic mean is used in preference to the geometric mean, even if the distribution is lognormal. This is because the geometric mean is lower than the arithmetic mean and therefore underestimates health risk. This underestimation becomes greater as the exposure variability increases (Mulhausen & Damiano, 1998, p. 133). There are several methods of calculating the mean, and the best one to use is the Mean Value Unbiased Estimator (MVUE) (Attfield & Hewett, 1992). This mean



is unbiased, has minimum variance and is good for sample sizes less than 20 with small geometric standard deviations. The MVUE can only be calculated for log-normal distributions.

2. 95% UCL Mean – this refers to the 95% Upper Confidence Limit of the mean. It is a value at which we can say with 95% confidence that the actual arithmetic mean lies below. If this value is below the exposure standard, then we can be 95% confident that the arithmetic mean exposure is also below the exposure standard.
3. Geometric Standard Deviation (GSD) – this figure represents the variability of each set of exposure data. The higher the GSD, the higher the variability. It is extremely useful in assessing whether or not the SEGs have been established correctly. If the GSD is too high, this is an indication that exposures are not as similar as first thought, and that reclassification may be required. The CEN recommends that the GSD should be less than three, if the group is to be classified as a SEG (European Committee for Standardization, 1995, p. 23). The UK Health and Safety Executive have stated that a useful rule of thumb is that “no individuals exposure should be less than half or greater than twice the group mean”(Health and Safety Executive, 1989, p. 44).

To provide additional information on the sources of this variation, each operator was required to complete a monitoring logsheet. These logsheets were developed after consultation with operators and were designed to record what the operator did during the monitoring period. These logsheets are shown in Appendix A.

4. Predicted Percent above Exposure Standard – this is a necessary statistic as it gives an indication of compliance on a shift to shift basis.

In cases where exposures for a SEG do not fit either a log-normal or normal distribution it is necessary to use simple descriptive statistics. These statistics simply describe the results obtained, and do not have any predictive capabilities, meaning that it is not possible to calculate figures such as the 95% UCL of the mean, or the predicted percentage of exposures which would be expected to exceed the exposure

standard. For the latter figure the only result that can be presented is simply the number of results above the exposure standard, divided by the total number of samples taken.

It is important to note that the distribution type affects the type of mean that is presented. Throughout this report, the mean is always referred to as the arithmetic mean. For log-normal distributions the arithmetic mean refers to the MVUE as outlined above. For normal distributions or data which does not fit either distribution, the mean is simply the calculated average of the results (i.e. the sum of all results divided by the number of results).

Having results below the limit of detection has implications for the manner in which they are analysed. A common way of dealing with these results is to assign them values equal to half the detection limit. However more advanced methods have been proposed. According to Mulhausen, a factor of 0.7 times the detection limit should be used if the data has a geometric standard deviation less than 3, and a factor of 0.5 times the detection limit should be used if the data has a geometric standard deviation greater than 3 (Mulhausen & Damiano, 1998, p. 129). Meanwhile, BOHS have recommended that a factor of 0.7 times the detection limit be used if the data is lognormally distributed, and a factor of 0.5 if the data follows a normal distribution (Guest et al., 1993, p. 62).

In this study, both of these methods will be combined. If the methods disagree, such as if the data is normally distributed and has a geometric standard deviation greater than 3, the higher factor will be used. If the data does not follow either distribution type, then again, the higher factor of 0.7 will be used.

More advanced methods of dealing with results below the limit of detection have been developed for distributions in which more than half of the samples fall into this category. These will not be explored here for practical reasons. If most results are below the detection limit, and if the detection limit is well below the exposure standard, then further analysis is not warranted as the exposure profile is obviously acceptable.

## **Monitoring Programs to Assess Risk of Short Term Health Effects**

For substances which can cause short term acute health effects, focussing on the mean exposure is not sufficient. It is far more important to focus on the maximum concentrations that individuals are exposed to (Mulhausen & Damiano, 1998, p. 136).

As discussed previously, substances which fall into this category are generally assigned either STEL or Peak exposure standards.

NOTE - For the purposes of this study, monitoring for substances with Peak exposure standards will be excluded, as no substances with these standards are present.

For those with a STEL, they will also have a TWA standard. This means that the monitoring has to achieve two aims, i.e. it has to provide an estimate of the mean exposure as well as an estimation of how high exposures can get.

There are two ways this can be done:

1. Use a statistical technique which uses TWA measurements (i.e. exposures averaged out over an entire work shift) to estimate the percentage of samples which would be expected to exceed the STEL. Such a method has been proposed by Rappaport et al for exposures which follow a log-normal distribution. This method is based upon the assumption that the “mean value and the frequency of large numbers are correlated (Rappaport, Selvin, & Roach, 1988, p. 310)”, and that by “constraining the mean exposure, one can simultaneously place an upper limit on the frequency of exposures of any averaging time which exceed a given value” (Rappaport et al., 1988, p. 311). This work is presented in Table 4 below.

Table 4

*The Maximum Fraction of Samples (1-f) which are Predicted to Exceed the Exposure Standard*

<b>Exposure standard / arithmetic mean</b>	<b>1-f (%)</b>
1	50
2	12
3	7
4	5
5	4
6	3
10	1.5

*Note*, 1-f = the maximal value.

(Grantham, 2001, p. 55)

For example, if the mean exposure equals 20 ppm and the STEL is equal to 200 ppm, then assuming that TWA exposures are kept below 20 ppm, then the proportion of 15 minute STEL readings which exceed the STEL will be no more than 1.5%.

It should be noted that “the value for 1-f is the maximal valued. It varies with the geometric standard deviation, and would be smaller if the geometric standard deviation were low (Grantham, 2001, p. 55)”

2. Use electronic monitoring instrumentation which can measure both TWA and STEL exposures simultaneously.

For this study, the second method will be used as the instrumentation calculates STEL exposures which make any statistical predictions redundant.

The other significant benefit with using electronic instrumentation is that it has the potential to data log and provide a computer printout of exposures over time. Instrumentation with this functionality was used in this study. This made it possible for high exposure tasks (i.e. tasks in which instantaneous concentrations exceed the TWA exposure standard) to be identified.

## Exposure to Multiple Atmospheric Contaminants

At Murrin Murrin, workers are exposed to several contaminants all of which have the potential to create adverse health effects. Depending upon how these contaminants interact with the body, the following effects are possible:

- Independent Actions – Each component acts in an individual way in the body which is different from, and unaffected by, the effects of the other components;
- Additive Actions – The combined toxic effects are the sum of the toxic effects of each component acting alone;
- Synergistic Actions – The combined toxic effects are greater than the simple sum of the toxic effects of the individual components acting alone (A special case arises when one component is essentially without a particular toxicity, but the combined effects are still greater than the sum of the individual effects. This is usually referred to as potentiation);
- Antagonistic Actions – The combined toxic effects are less than the simple sum of the toxic effects of each component acting alone.

(Guest et al., 1993, p. 15)

Obviously as the number of contaminants increases, so does the complexity of predicting the final health outcome. Adding to this complexity is a lack of knowledge relating to exposure to mixtures. This knowledge gap has been recognised by NIOSH who have recommended further research in specific areas (Department of Health and Human Services, 2004).

In this document NIOSH outline ten potential methods for dealing with exposure to mixtures including the whole mixture approach (i.e. treat the mixture as a single entity and conduct a health risk assessment on it), similar mixture approach (i.e. estimate health risk from similar mixtures which have already been studied), hazard index (i.e. adds up the ratio of exposure to exposure standard for all components of the mixture), etc.

Most of these methods are extremely complex and would require expert assistance and significant amounts of research to implement. As a result, the method used in this study was the hazard index which is calculated by adding the ratios of each exposure to the exposure standard as follows:

$$C1/ES1 + C2/ES2 + \dots Cn/ES1$$

Where C = Concentration and ES = Exposure Standard

If the result is greater than one, then the exposure is deemed to be unacceptable.

According to NOHSC, this method is applicable when the components of the mixture are acting on the same target organ and the effects are believed to be additive. The example they give is for a selection of solvents which all act on the central nervous system (National Occupational Health and Safety Commission, 1995a, p. 27).

This distinction relating to similarity of target organs is not made by BOHS (Guest et al., 1993, p. 15). Instead they simply add up the ratios for each component regardless of their health effects. This approach probably stems from the complete lack of specific knowledge relating to synergistic, antagonistic, independent and additive effects. Assuming that all effects are additive is therefore a conservative approach to exposure assessment, even if it does have the following shortcomings identified by BOHS (Guest et al., 1993):

- 1) This method was designed to be used for health effects arising as a result of exposure frequency, not from effects arising from contaminants with varying severities of effect;
- 2) The equation may not be applicable to the effects of long-term, low level exposures, or some types of delayed effects;
- 3) Exposure standards evolve with increasing knowledge and changing perceptions of acceptable risk;
- 4) Different contaminants may have different types of exposure standards;
- 5) Different components of this mixture may effect different target organs.

(Guest et al., 1993, p. 15-16)

In the absence of more accurate measures, the hazard index will be used in this study to assess exposure in instances where employees are exposed to more than one contaminant.

## **CHAPTER 4 – RESULTS**

The aim of this chapter is to present the collected data in a summarised form relating to the research hypotheses.

### **Hypothesis Part 1 - Chemical Hazards at Murrin Murrin Had Not Been Adequately Identified**

This is the simplest of the three hypotheses to present results for. The reason for this is that no comprehensive hazard identification process had ever been completed prior to this study. As such, the only results to present are those collected for this purpose.

The manner in which the hazard identification process was conducted is outlined in Chapter 3, and a complete listing of all chemical hazards is shown in the following tables.

Table 5

*List of Chemicals Identified in Utilities*

Soda Ash	Nalco 7330
Permatreat PC510	Nalco 73201
MT3100	Sodium Hydroxide (48%)
Bioclean-LF	Stabrex ST70
Citra Clean 4	Nalco 356
Mem-clean A 10	Nalco 7208
Cation Resin Amberjet 1200H	Nalco Eliminox
Anion Resin Amberjet 4200CL	Diesel
Dust-Seal 81620	Hydrogen Sulphide
Sulphuric Acid (23%)	Sulphur Dioxide
Sodium Hydroxide (46%)	Sulphur Trioxide / Sulphuric Acid Mist
Sodium Hydroxide (23%)	Diatomaceous Earth
Chlorine	Lime, hydrated
Nalco 7392	Sulphur
Nalco 8338	



Table 6

*List of Chemicals Identified in Ore Leach*

Sulphur	Magnafloc 800HP
Nickel Refinery Tailings (KNR)	Hydrochloric Acid (5%)
Kambalda Nickel Hydroxide (KNO)	Calcrete Slurry
Iron Cake	Carbon Dioxide
Copper Cake	Zinc Sulphate
DP1 – 8468	General Steam
Demister Wash Fallout	Condensate
Hydrogen Sulphide	Neutralised Barren Liquor
98% Sulphuric Acid	Strong Plate Liquor
Sulphuric Acid Mist	Copper Sulphate
Sodium Hydroxide (Caustic)	Gypsum (in solution)
Nitrogen	Pressure Leach Solution (Leach slurry)
Inert Gas	Tails Solution
Magnafloc LT35 (now called Magnafloc LT425)	

Table 7

*List of Chemicals Identified in Refinery*

Aqueous Ammonia (28%) (weak)	Copper Cake
Sulphuric Acid (98%)	Iron Cake
Nickel Powder	Cobalt Powder
Nickel Briquettes	Cobalt Briquettes
Ferrous Sulphate Heptahydrate	Shellsol 2046
Aluminium Sulphate	Cyanex 272 (ortho phosphinic acid)
Hydrogen Sulphide	Tri-butyl Phosphate (TBP)
Polyacrylic Acid (Alcotac CB8)	Butyl-hydroxy Toluene (BHT)
Perflo AP20 (Perlite)	Sulphuric Acid (120g/L)
Hydrogen	Sulphuric Acid (180g/L)
Nitrogen	Dilute Aqueous Ammonia (67g/L)
Nickel Sulphate	Zinc Sulphate
Anhydrous Ammonia	Cobalt Sulphate
Magnafloc E10	Hydrogen Peroxide
Sodium Hydroxide (50%)	Ammonia
Sodium Cyanide	Sulphur Dioxide
Sodium Sulphide	Ferric Sulphate
Ammonium Sulphate	Natural Gas
Mixed Sulphides	

## **Hypothesis Part 2 - The current occupational hygiene monitoring protocols did not adequately quantify worker exposures to these chemical hazards**

From the above list of potential chemical hazards, it was necessary to identify those for which hygiene monitoring would be required. A full listing of each of these chemicals, and the justification for either including or eliminating each one from the monitoring program can be seen in Tables 8a and b, 9a and b and 10a and b below (due to the amount of information being presented each table has been split into two sections).

It should be noted that these tables do not list all of the information that was collected in accordance with what was stated in Chapter 2. Some of this information was not relevant for justifying a monitoring program, and as a consequence, has been omitted.

Table 8a

*Utilities – Justification for Monitoring Program*

<b>Chemical</b>	<b>Use</b>	<b>Health effects</b>	<b>Who is exposed?</b>	<b>How can exposure occur?</b>
Soda Ash	pH control of potable water	Respiratory and skin irritant, as well as severe eye irritant due to corrosive properties	43/4400 Operator	When tipping bags into process
Permatreat PC-510	RO anti-scalent	Eye and skin irritant	43/4400 Operator	When decanting from bulky <sup>a</sup> into anti-scalent dosing tank
MT3100	Acid clean RO membranes	Highly corrosive to eyes, skin and respiratory tract	Occtech	When cleaning RO membranes
Bioclean-LF	Alkaline clean RO membranes	Respiratory, eye and skin irritant due to slight corrosive properties	Occtech	When cleaning RO membranes

<b>Chemical</b>	<b>Use</b>	<b>Health effects</b>	<b>Who is exposed?</b>	<b>How can exposure occur?</b>
Citra Clean 4	Cleans cartridge filter	Slight eye irritant with direct contact.	43/4400 Operator	During cleaning
Memclean A10	Cleans cartridge filter	Eye and skin irritant, plus a minor respiratory irritant.	43/4400 Operator	During cleaning
Cation Resin Amberjet 1200H	Mixed bed exchanger	Low to moderate respiratory, skin and eye irritant	43/4400 Operator	During exchanger change
Anion Resin Amberjet 4200CL	Mixed bed exchanger	Low to moderate respiratory, skin and eye irritant	43/4400 Operator	During exchanger change
Dust Seal 81620	Dust suppressant for sulphur stockpile	Can irritate eyes and skin. Can be a respiratory irritant, but unlikely as it is in solution	Brambles	During application

<b>Chemical</b>	<b>Use</b>	<b>Health effects</b>	<b>Who is exposed?</b>	<b>How can exposure occur?</b>
Sulphuric Acid (23%)	Mixed bed exchanger	Severe respiratory, eye and skin irritant due to corrosive properties	43/4400 Operator	Filled from acid plant tank. Exposure could occur as a result of line breakage
Sodium Hydroxide (46%)	Bulk store. Pumped to specific areas of plant for use.	Severe respiratory, eye and skin irritant due to corrosive properties	Tanker driver	During tanker unloading
Sodium Hydroxide (23%)	Mixed bed exchanger	Severe respiratory, eye and skin irritant due to corrosive properties	43/4400 Operator	Equipment failure or line breakage
Chlorine	Microbiological control for potable water	Severe eye and skin irritant, plus highly toxic inhalation hazard	43/4400 Operator	If there is a leak when changing cylinders

<b>Chemical</b>	<b>Use</b>	<b>Health effects</b>	<b>Who is exposed?</b>	<b>How can exposure occur?</b>
Nalco 7392	Maintenance of zinc and phosphate levels in cooling towers	Respiratory, eye and skin irritant due to slight corrosive properties	43/4400 Operator	During decanting of bulkies <sup>a</sup>
Nalco 8338	Used when Koorang water added to cooling tower	Respiratory, eye and skin irritant due to corrosive properties. Inhalation risk is minimal due to low vapour pressure.	43/4400 Operator	During decanting of bulkies <sup>a</sup>
Nalco 7330	Microbiocide	Respiratory and skin irritant, plus severe eye irritant. Inhalation risk is minimal due to low vapour pressure	43/4400 Operator	During decanting of bulkies <sup>a</sup>

<b>Chemical</b>	<b>Use</b>	<b>Health effects</b>	<b>Who is exposed?</b>	<b>How can exposure occur?</b>
Nalco 73201	Dispersant	Respiratory, eye and skin irritant. Inhalation risk is minimal due to low vapour pressure	43/4400 Operator	During decanting of bulkies <sup>a</sup>
Sodium Hydroxide (48%)	pH control	Severe respiratory, eye and skin irritant due to corrosive properties	43/4400 Operator	During decanting of bulkies <sup>a</sup>
Stabrex ST70	Antimicrobial	Severe respiratory and eye irritant, and will also irritate skin	43/4400 Operator	During decanting of bulkies <sup>a</sup>
Nalco 356	Anticorrosion agent in boilers	Severe respiratory and eye irritant, and will also irritate skin. Can be absorbed through the skin	43/4400 Operator	During decanting of bulkies <sup>a</sup>



<b>Chemical</b>	<b>Use</b>	<b>Health effects</b>	<b>Who is exposed?</b>	<b>How can exposure occur?</b>
Nalco 7208	pH and phosphate control	Severe eye and skin irritant, and will also irritate the respiratory tract	43/4400 Operator	During decanting of bulkies <sup>a</sup>
Nalco Elimin-ox	Oxygen scavenger	Low level respiratory, skin and eye irritant	43/4400 Operator	During decanting of bulkies <sup>a</sup>
Diesel	Fuel for generators	Eye and skin irritant, and toxic (narcotic) via inhalation. Has a carcinogenicity classification	41/5100 Operator	Filled from another tank and gravity fed to generators. Exposure could occur due to a line breakage

<b>Chemical</b>	<b>Use</b>	<b>Health effects</b>	<b>Who is exposed?</b>	<b>How can exposure occur?</b>
Hydrogen Sulphide	Plant reagent which is produced on site	Highly toxic via inhalation, and severe eye irritant due to corrosive properties	41/5100 Operator	Adding diatomaceous earth to precoat pit, changing sulphur filters and leaks from H <sub>2</sub> S plant
			Brambles loader driver	Digging out dirty sulphur from blowdown pit
Sulphur Dioxide	Interim product of sulphuric acid production	Severe eye irritant, and also irritating to respiratory tract	41/5100 Operator	Adding diatomaceous earth to precoat pit, changing sulphur filters and leaks from H <sub>2</sub> S plant
			Brambles loader driver	Digging out dirty sulphur from blowdown pit

<b>Chemical</b>	<b>Use</b>	<b>Health effects</b>	<b>Who is exposed?</b>	<b>How can exposure occur?</b>
Sulphur Trioxide / Sulphuric Acid Mist	Interim product of sulphuric acid production. Sulphur trioxide reacts with moisture in the air to form sulphuric acid mist	Severe respiratory, eye and skin irritant due to corrosive properties. Sulphuric acid mist has a carcinogenicity classification	41/5100 Operator	Leaks from acid plant.
Diatomaceous earth	Used in sulphur filters	Low level respiratory, eye and skin irritant. Contains crystalline silica which has a carcinogenicity classification	41/5100 Operator	When adding material to precoat pit during filter changes
Hydrated Lime	pH control	Severe eye and respiratory irritant, and also irritating to the skin due to corrosive properties	4100/5100 Operator Brambles delivery driver	Material blown off conveyor During truck unloading

<b>Chemical</b>	<b>Use</b>	<b>Health effects</b>	<b>Who is exposed?</b>	<b>How can exposure occur?</b>
Sulphur	Raw material for acid plant	Respiratory, eye and skin irritant due to corrosive properties.	41/5100 Operator Brambles loader driver Brambles delivery driver	Windblown dust Dust generation while driving loader in stockpile Dust generation when unloading sulphur truck

<sup>a</sup> bulky or bulkies refers to a specific type of storage container

Table 8b

*Utilities – Justification for Monitoring Program*

<b>Chemical</b>	<b>Frequency of exposure</b>	<b>Existing exposure controls (in addition to standard site PPE and equipment)</b>	<b>Atmospheric monitoring required?</b>
Soda Ash	1/shift	Gloves	No. Exposure duration is too short to warrant monitoring

<b>Chemical</b>	<b>Frequency of exposure</b>	<b>Existing exposure controls (in addition to standard site PPE and equipment)</b>	<b>Atmospheric monitoring required?</b>
Permatreat PC-510	1/fortnight	None	No. Inhalation risk is low due to low vapour pressure
MT3100	As required	Barricading plus additional PPE used by Occtech	No. Contractors are not included in this study
Bioclean-LF	As required	Barricading plus additional PPE used by Occtech	No. Contractors are not included in this study
Citra Clean 4	As required	Gloves	No. Does not present an inhalation hazard
Memclean A10	As required	Gloves	No. Does not present a significant inhalation hazard
Cation Resin Amberjet 1200H	Every 2 years		No. Maintenance activities are not included in this study
Anion Resin Amberjet 4200CL	Every 2 years		No. Maintenance activities are not included in this study

<b>Chemical</b>	<b>Frequency of exposure</b>	<b>Existing exposure controls (in addition to standard site PPE and equipment)</b>	<b>Atmospheric monitoring required?</b>
Dust Seal 81620	No longer used	Disposable overalls, gloves	No. No longer used
Sulphuric Acid (23%)	Unpredictable		No. Monitoring program can not be developed for unpredictable exposures
Sodium Hydroxide (46%)	Unpredictable		No. Monitoring program can not be developed for unpredictable exposures
Sodium Hydroxide (23%)	Unpredictable		No. Monitoring program can not be developed for unpredictable exposures
Chlorine	Cylinders are changed every 3 months	Follow requirements of AS2927	No. Due to severe toxicity, exposures need to be controlled by procedures and PPE.
Nalco 7392	1/month		No. Decanting occurs in open air so high concentrations are unlikely. Also, exposure is only once/month

<b>Chemical</b>	<b>Frequency of exposure</b>	<b>Existing exposure controls (in addition to standard site PPE and equipment)</b>	<b>Atmospheric monitoring required?</b>
Nalco 8338	Infrequent		No. Inhalation risk is not significant, and product is used infrequently
Nalco 7330	1/month		No. Inhalation risk is not significant
Nalco 73201	1/month		No. Inhalation risk is not significant
Sodium Hydroxide (48%)	1/month		No. Decanting occurs in open air so high concentrations are unlikely. Also, exposure is only once/month
Stabrex ST70	1/month		No. Decanting occurs in open air so high concentrations are unlikely. Also, exposure is only once/month
Nalco 356	1/month		No. Decanting occurs in open air so high concentrations are unlikely. Also, exposure is only once/month

<b>Chemical</b>	<b>Frequency of exposure</b>	<b>Existing exposure controls (in addition to standard site PPE and equipment)</b>	<b>Atmospheric monitoring required?</b>
Nalco 7208	1/month		No. Decanting occurs in open air so high concentrations are unlikely. Also, exposure is only once/month
Nalco Elimin-ox	1/month		No. Inhalation risk is not significant due to low vapour pressure
Diesel	Unpredictable		No. Monitoring program can not be developed for unpredictable exposures
Hydrogen Sulphide	2/shift (precoat pit)	Full-face respirators used over precoat pit.	Yes. Monitoring is required to identify high exposure tasks
Sulphur Dioxide	2/shift (precoat pit)	Full-face respirators used over precoat pit.	Yes. Monitoring is required to identify high exposure tasks



<b>Chemical</b>	<b>Frequency of exposure</b>	<b>Existing exposure controls (in addition to standard site PPE and equipment)</b>	<b>Atmospheric monitoring required?</b>
Sulphur Trioxide / Sulphuric Acid Mist	Unpredictable	Emissions are visible so controls can be implemented as required	Yes. These emissions are generally visible and therefore avoidable. However, sulphuric acid has a carcinogenicity classification, so it is necessary to confirm whether or not exposures are occurring
Diatomaceous earth	2/shift	Full face respirator	Yes. Needs to be assessed due to its carcinogenicity classification. Monitor for respirable dust and analyse samples for crystalline silica
Hydrated Lime	Unpredictable for 41/5100 operator.  As required for Brambles driver.		Yes. Simple addition to dust monitoring program. Monitor for inhalable dust and analyse samples for lime (calcium hydroxide)

<b>Chemical</b>	<b>Frequency of exposure</b>	<b>Existing exposure controls (in addition to standard site PPE and equipment)</b>	<b>Atmospheric monitoring required?</b>
Sulphur	Unpredictable for 41/5100 operator.  As required for Brambles loader driver and delivery driver.		Yes. Simple addition to dust monitoring program. Monitor for inhalable dust and analyse samples for sulphur

*Note,* Standard site PPE includes long sleeved shirt, trousers, steel capped boots, safety glasses or monogoggles, half-face respirator, hydrogen sulphide gas monitor and hard hat. Standard site equipment includes safety shower / eye wash stations and local area gas detectors and alarms.

Table 9a

*Ore Leach – Justification for Monitoring Program*

<b>Chemical</b>	<b>Use</b>	<b>Health effects</b>	<b>Who is exposed?</b>	<b>How can exposure occur?</b>
Sulphur	Mill feed. Controls EH for autoclaves	Respiratory, eye and skin irritant	3100 Operator	During loading onto conveyor from ROM to mill
Nickel Refinery Tails (KNR)	Feed additive	Respiratory, eye and skin irritant. Contains small percentage of arsenic. Contains nickel which has a carcinogenicity classification	3100 Operator	When working under sizer

<b>Chemical</b>	<b>Use</b>	<b>Health effects</b>	<b>Who is exposed?</b>	<b>How can exposure occur?</b>
Kambalda Nickel Hydroxide (KNO)	Feed additive	Moderate respiratory, eye and skin irritant. Contains nickel which has a carcinogenicity classification. May contain heavy metals	3100 Operator	When working under sizer
Iron Cake	Feed additive – recycled waste product from plant	Respiratory, eye and skin irritant. Contains nickel which has a carcinogenicity classification	3100 Operator	When working under sizer

<b>Chemical</b>	<b>Use</b>	<b>Health effects</b>	<b>Who is exposed?</b>	<b>How can exposure occur?</b>
Copper Cake	Feed additive – recycled waste product from plant	Respiratory, eye and skin irritant. Contains nickel which has a carcinogenicity classification	3100 Operator	When working under sizer
DP1 - 8468	Flocculant	Low level respiratory, eye and skin irritant	Nil. Material is automatically loaded and mixed	Exposure is not expected to occur
Demister wash fallout	Demister wash	Potential irritant due to possible acidity. Contains sulphuric acid which has a carcinogenicity classification	Predominantly 3200 Operators, although has the potential to effect operators in nearby areas	Demister pad washing causes slurry to be ejected from stacks

<b>Chemical</b>	<b>Use</b>	<b>Health effects</b>	<b>Who is exposed?</b>	<b>How can exposure occur?</b>
Hydrogen sulphide	Reduction agent	Highly toxic via inhalation. Severe eye irritant due to corrosive properties	3400 / 3510 Operator	Overgassing and line failure
Sulphuric Acid Solution (98%)	Used to leach metals from the ore	Severe eye, skin and respiratory irritant due to corrosive properties. Sulphuric acid has a carcinogenicity classification	3200 Operators	Line or pump failure
Sulphuric Acid Mist	Potentially emitted from 3200 stacks and 3300 CCD's	Severe respiratory irritant. Sulphuric acid has a carcinogenicity classification	3200 and 3300 operators. May also effect 3100 and 3400/3510 operators	Continuous emissions from stacks and CCD's

<b>Chemical</b>	<b>Use</b>	<b>Health effects</b>	<b>Who is exposed?</b>	<b>How can exposure occur?</b>
Nitrogen	Blanketing and purging gas for autoclaves	Asphyxiant gas	Nil. Exposures are not expected	Line failure
Inert Gas	Produced in process	Asphyxiant gas containing nitrogen and carbon dioxide	Nil. Exposures are not expected	Line failure
Magnafloc LT35 (now called Magnafloc LT425)	Coagulant in CCD2	Low level respiratory, eye and skin irritant	3300 Operator Truck Driver  Ore Leach Operator	When disconnecting pipes  When transferring from truck to plant  When collecting from stores
Magnafloc 800HP	Flocculant in 33-BN-01	Low level respiratory, eye and skin irritant	Truck Driver  Ore Leach Operator	During loading  When collecting from stores

<b>Chemical</b>	<b>Use</b>	<b>Health effects</b>	<b>Who is exposed?</b>	<b>How can exposure occur?</b>
Hydrochloric Acid (5%)	Cleaning instruments	Severe eye, skin and respiratory irritant due to corrosive properties	3300 Operator or Process Engineer	Spillage
Calcrete Slurry	Neutralising agent		3300 and 3400/3510 Operators	Line or valve failure
Carbon Dioxide	By-product of neutralisation process	Asphyxiant gas	3300 and 3400/3510 Operators	Line or valve failure
Zinc Sulphate	Wast product from Refinery (3900) which is pumped into 33-TK-53 A & B	Potential skin and eye irritant due to sulphuric acid content (80g/L)	3300 Operators	Line or valve failure
General Steam	Used for heating	Potential burns	3100, 3200, 3300 and 3400/3510 Operators	Broken line Any activity involving direct contact



<b>Chemical</b>	<b>Use</b>	<b>Health effects</b>	<b>Who is exposed?</b>	<b>How can exposure occur?</b>
Condensate	Condensed steam from the process	Potential burns	3100, 3200, 3300 and 3400/3510 Operators	Broken line  Any activity involving direct contact
Neutralised Barren Liquor	3300 wash solution pumped from Refinery (3500)	Eye and skin irritant (assumed as no health data was available)	3300 Operators	Broken line
Strong Plate Liquor	Transferred from Refinery to the containment pond via truck	Eye and skin irritant (assumed as no health data was available)	Refinery Operator	Broken line  When transferring solution via truck
Copper Sulphate	Transferred from Refinery to containment pond via truck	Low level respiratory, eye and skin irritant	Refinery Operator	Transfer line failure  Spill during transfer
Gypsum	By-product of calcrete addition	Low level respiratory, eye and skin irritant	3400 Operator	Line failure

<b>Chemical</b>	<b>Use</b>	<b>Health effects</b>	<b>Who is exposed?</b>	<b>How can exposure occur?</b>
Pressure Leach Solution (Leach Slurry)	The “product” from 3200 autoclaves	Assumed to be an eye and skin irritant due to its potential acidity.	3200, 3300 and 3400/3510 Operators	Line failure  During sampling
Tails Solution	Waste	Assumed to be an eye and skin irritant (no health data available)	3300 and 7700 Operators	Line failure  Moving pipes at tailings dam

Table 9b

*Ore Leach – Justification for Monitoring Program*

<b>Chemical</b>	<b>Frequency of exposure</b>	<b>Existing exposure controls (in addition to standard site PPE and equipment)</b>	<b>Atmospheric monitoring required?</b>
Sulphur	Loaded onto conveyor 2/day	Enclosed cab on loader	Yes. Simple addition to dust monitoring program. Monitor for inhalable dust and analyse samples for sulphur
Nickel Refinery Tails (KNR)	30t added per 1000t/ore	P2 respirator worn when working under sizer	Yes. Contains arsenic which is a heavy metal and nickel which has a carcinogenicity classification. Monitor for inhalable dust and analyse samples for nickel and heavy metals

<b>Chemical</b>	<b>Frequency of exposure</b>	<b>Existing exposure controls (in addition to standard site PPE and equipment)</b>	<b>Atmospheric monitoring required?</b>
Kambalda Nickel Hydroxide (KNO)	30t added per 1000t/ore	P2 respirator worn when working under sizer	Yes. May contain heavy metals and contains nickel which has a carcinogenicity classification. Monitor for inhalable dust and analyse samples for nickel and heavy metals
Iron Cake	10t added per 2400t/ore	P2 respirator worn when working under sizer	Yes. Contains nickel which has a carcinogenicity classification. Monitor for inhalable dust and analyse samples for nickel
Copper Cake	10t added per 2400t/ore	P2 respirator worn when working under sizer	Yes. Contains nickel which has a carcinogenicity classification. Monitor for inhalable dust and analyse samples for nickel

<b>Chemical</b>	<b>Frequency of exposure</b>	<b>Existing exposure controls (in addition to standard site PPE and equipment)</b>	<b>Atmospheric monitoring required?</b>
DP1 - 8468	Exposure is not expected to occur		No. Exposure is not expected to occur
Demister wash fallout	4 / day	All personnel are notified to exit the area prior to the demister wash occurring	Yes. Contains sulphuric acid which has a carcinogenicity classification and heavy metals. Monitor for sulphuric acid mist and inhalable dust. Analyse inhalable dust samples for heavy metals
Hydrogen sulphide	Unpredictable		Yes. Monitoring is required to identify high exposure tasks
Sulphuric Acid Solution (98%)	Exposures occur due to equipment failure and are unpredictable		No. Monitoring program can not be developed for unpredictable exposures

<b>Chemical</b>	<b>Frequency of exposure</b>	<b>Existing exposure controls (in addition to standard site PPE and equipment)</b>	<b>Atmospheric monitoring required?</b>
Sulphuric Acid Mist	Potentially continuous and will depend on time spent in the outlined areas and the weather conditions	Process controlled to reduce acidity in CCD's	Yes. Sulphuric acid has a carcinogenicity classification. Monitor for sulphuric acid mist
Nitrogen	Unpredictable	Vented through 4m high stacks. Incoming nitrogen is piped directly from the BOC plant	No. Monitoring program can not be developed for unpredictable exposures
Inert Gas	Unpredictable		No. Monitoring program can not be developed for unpredictable exposures
Magnafloc LT35 (now called Magnafloc LT425)	Unpredictable for 3300 Operator 1-3/month for Truck Driver 1-2/week for Ore Leach Operator	Gloves Material unloaded from truck to plant as a liquid	No. Delivered as a liquid so there is no inhalation hazard

<b>Chemical</b>	<b>Frequency of exposure</b>	<b>Existing exposure controls (in addition to standard site PPE and equipment)</b>	<b>Atmospheric monitoring required?</b>
Magnafloc 800HP	1-2/week for Truck Driver  1/week for Ore Leach Operator		No. Truck driver is a contractor and therefore not included in this study
Hydrochloric Acid (5%)	Unpredictable	Gloves	No. There is no inhalation hazard
Calcrete Slurry	Unpredictable		No. There is no inhalation hazard as the calcrete is mixed with water
Carbon Dioxide	Unpredictable	Vented off through 5m high stacks in 3400  Seal pots on tank overflows	No. Risk is insignificant
Zinc Sulphate	Unpredictable		No. There is no inhalation risk
General Steam	Unpredictable		No. There is no inhalation risk
Condensate	Unpredictable		No. There is no inhalation risk

<b>Chemical</b>	<b>Frequency of exposure</b>	<b>Existing exposure controls (in addition to standard site PPE and equipment)</b>	<b>Atmospheric monitoring required?</b>
Neutralised Barren Liquor	Unpredictable		No. There is no inhalation risk
Strong Plate Liquor	During solution transfer which occurs 2-3/week		No. There is no inhalation risk
Copper Sulphate	Transfer occurs 2-3/week		No. Inhalation risk is insignificant
Gypsum	Unpredictable		No. Gypsum is in solution so there is no inhalation risk
Pressure Leach Solution (Leach Slurry)	Unpredictable  Spills during sampling		No. There is no inhalation risk
Tails Solution	Unpredictable		No. There is no inhalation risk

*Note*, standard site PPE includes long sleeved shirt, trousers, steel capped boots, safety glasses or monogoggles, half-face respirator, hydrogen sulphide gas monitor and hard hat. Standard site equipment includes safety shower / eye wash stations and local area gas detectors and alarms.



Table 10a

*Refinery – Justification for Monitoring Program*

<b>Chemical</b>	<b>Use</b>	<b>Health effects</b>	<b>Who is exposed?</b>	<b>How can exposure occur?</b>
Aqueous Ammonia (28%) (weak)	pH control	Severe respiratory, eye and skin irritant due to corrosive properties	3700, 3800 and 3900 Operators	Line failure Taking samples
Sulphuric Acid (98%)	pH control Make-up strip solution Process liquor	Severe respiratory, eye and skin irritant due to corrosive properties	3700, 3900, 3500 and 3600 Operators	Line failure Leaks Mixing catalyst
Nickel Powder	Interim product before briquetting	Respiratory, eye and skin irritant.  Nickel has a carcinogenicity classification	3700 Furnace and Packaging Operators	Powder escapes at several points in the process

<b>Chemical</b>	<b>Use</b>	<b>Health effects</b>	<b>Who is exposed?</b>	<b>How can exposure occur?</b>
Nickel Briquettes	Final Product	Skin irritant	3700 Furnace and Packaging Operators	Cleaning Packaging Shed. Routine work practices
Ferrous Sulphate Heptahydrate	Nucleation Catalyst	Respiratory, eye and skin irritant	3700 Operators	When mixing catalyst
Aluminium Sulphate	Nucleation Catalyst	Respiratory, eye and skin irritant	3700 Operators	When mixing catalyst
Hydrogen Sulphide	Recovery of residual nickel and cobalt from autoclaves	Highly toxic via inhalation. Severe eye irritant due to corrosive properties	3700 Operators	Line failure
	Precipitates solids		3500 Operators	Line failure and stack emissions
			3600 Operators	Line failure

<b>Chemical</b>	<b>Use</b>	<b>Health effects</b>	<b>Who is exposed?</b>	<b>How can exposure occur?</b>
Polyacrylic Acid (Alcotac CB8)	Briquette binder and nucleation catalyst	Low level respiratory, skin and eye irritant	3700 and 3800 Operators	Filling hopper that feeds mill  Line failure  Mixing nucleation catalyst
Perflo AP20 (Perlite)	Filter pre-coat	Respiratory, eye and skin irritant. May contain crystalline silica at a concentration of less than 0.1%	3600 and 3700 Operators	When mixing
Hydrogen	Reducing gas in autoclaves	Asphyxiant gas	3700 and 3800 Operators	Line failure
Nitrogen	Purging gas for furnace  Blanketing gas in tanks	Asphyxiant gas	3500, 3600, 3700 and 3800 Operators	Line failure
Nickel Sulphate	Intermediate product	Eye and skin irritant	3600 and 3900 Operators	Line failure

<b>Chemical</b>	<b>Use</b>	<b>Health effects</b>	<b>Who is exposed?</b>	<b>How can exposure occur?</b>
Anhydrous Ammonia	pH control	Severe respiratory, eye and skin irritant due to corrosive properties	3700 and 3800 Operators	Line failure
	Process addition		5900 and Packaging Operators	When unloading truck and line failure
Magnafloc E10	Flocculant	Low level respiratory, eye and skin irritant	3500 and 3700 Operators	Filling hopper and when mixing
	Thickening agent			
Sodium Hydroxide (50%)	Nucleation catalyst	Severe respiratory, eye and skin irritant due to corrosive properties	3800 Operators	Opening containers when mixing catalyst
Sodium Cyanide	Nucleation catalyst	Highly toxic via inhalation, ingestion and skin contact. Corrosive to the eyes	3800 Operators	Opening containers when mixing catalyst

<b>Chemical</b>	<b>Use</b>	<b>Health effects</b>	<b>Who is exposed?</b>	<b>How can exposure occur?</b>
Sodium Sulphide	Nucleation catalyst	Highly corrosive to the eyes, corrosive to the skin, and slightly corrosive via inhalation	3800 Operators	Opening containers when mixing catalyst
Ammonium Sulphate	Waste product which is sold	Low level respiratory, eye and skin irritant	5900 Operators	When working in AMSUL shed
Mixed Sulphides	Final product from 3500 Production by-product	Respiratory, eye and skin irritant. Contains nickel and cobalt which have carcinogenicity classifications	3500 and 3600 Operators	When bagging mixed sulphides.  If it dries on ground following a release from the process

<b>Chemical</b>	<b>Use</b>	<b>Health effects</b>	<b>Who is exposed?</b>	<b>How can exposure occur?</b>
Copper Cake	Waste product	Respiratory, eye and skin irritant. Contains nickel which has a carcinogenicity classification	3500 and 3600 Operators	When working near dry material around the “squash court” area
Iron Cake	Waste product	Respiratory, eye and skin irritant. Contains nickel which has a carcinogenicity classification	3500 and 3600 Operators	When working near dry material around the “squash court” area
Cobalt Powder	Intermediate product/Final product	Respiratory, eye and skin irritant. Cobalt has a carcinogenicity classification	3800 Operators and Packaging Operators	When working in Area 3800  When packing powder into drums

<b>Chemical</b>	<b>Use</b>	<b>Health effects</b>	<b>Who is exposed?</b>	<b>How can exposure occur?</b>
Cobalt Briquettes	Final product	Skin irritant	3800 Operators and Packaging Operators	When working in Area 3800  When packing powder into drums
Shellsol 2046	Organic make-up in Area 3900	Respiratory, eye and skin irritant. Chronic exposure may cause damage to the auditory and central nervous systems	3900 Operators	When working in Area 3900, especially when taking samples on the top level (crud harvesting)
Cyanex 272 Extractant	Additive to solvent extraction process	Respiratory, eye and skin irritant.	3900 Operators	When working in Area 3900, especially when taking samples on the top level (crud harvesting)

<b>Chemical</b>	<b>Use</b>	<b>Health effects</b>	<b>Who is exposed?</b>	<b>How can exposure occur?</b>
Tributyl Phosphate	Additive to solvent extraction process	Eye and skin irritant. Slightly toxic via inhalation	3900 Operators	When working in Area 3900, especially when taking samples on the top level (crud harvesting)
Butylated Hydroxy Toluene (BHT)	Additive to solvent extraction process	Respiratory, eye and skin irritant.	3900 Operators	When working in Area 3900, especially when taking samples on the top level (crud harvesting)
Sulphuric Acid (120g/L)	Strip solution Used for cleaning pan	Severe respiratory, eye and skin irritant due to corrosive properties	3900 and 3800 Operators	When taking samples (3900) or pouring solutions (3800)
Sulphuric Acid (180g/L)	Strip solution	Severe respiratory, eye and skin irritant due to corrosive properties	3900 Operators	When taking samples



<b>Chemical</b>	<b>Use</b>	<b>Health effects</b>	<b>Who is exposed?</b>	<b>How can exposure occur?</b>
Dilute Aqueous Ammonia (67g/L)	pH adjustment	Severe respiratory, eye and skin irritant due to corrosive properties	3900 Operators	When taking samples
Zinc Sulphate	Waste solution	Eye and skin irritant	3900 Operators	Leaks Taking samples
Cobalt Sulphate	Intermediate product form 3900	Eye and skin irritant	3900 Operators	Leaks Taking samples
Hydrogen Peroxide	Neutralising agent for hydrogen sulphide	Severe respiratory, eye and skin irritant due to corrosive properties	3500 Operators	Line failure
Ammonia	Condi from 3700 used in tower mill Re-agent in 3600	Severe respiratory, eye and skin irritant due to corrosive properties	3500 and 3600 Operators. Can also be released in Area 5900	Line failure

<b>Chemical</b>	<b>Use</b>	<b>Health effects</b>	<b>Who is exposed?</b>	<b>How can exposure occur?</b>
Sulphur Dioxide	Leak testing during transfer of ammonia	Severe eye irritant, and also irritating to respiratory tract	5900 Operator	Opening gas bottle
Ferric Sulphate	Washing of heat exchangers	Respiratory, eye and skin irritant	3500 Operator	Line failure
Natural Gas	Fuel for furnace burners Fuel for flare	Asphyxiant gas	3800 and 3500 Operators	Line failure
General dust blowing throughout the Refinery		May contain nickel and cobalt which have carcinogenicity classifications	All refinery operators	When working in Refinery

Table 10b

*Refinery – Justification for Monitoring Program*

<b>Chemical</b>	<b>Frequency of exposure</b>	<b>Existing exposure controls (in addition to standard site PPE and equipment)</b>	<b>Atmospheric monitoring required?</b>
Aqueous Ammonia (28%) (weak)	Daily while taking samples	Procedures	No. Exposures are either unpredictable or very brief
Sulphuric Acid (98%)	Depends upon task.		No. There is no inhalation hazard as it is not present as a mist
Nickel Powder	Continuous whilst working in effected areas	P2 respirators are mandatory when entering the 3700 Packaging Shed	Yes. Nickel has a carcinogenicity classification. Monitor for inhalable dust and analyse samples for nickel
Nickel Briquettes	Frequent		No. Does not pose an inhalation hazard in briquette form

<b>Chemical</b>	<b>Frequency of exposure</b>	<b>Existing exposure controls (in addition to standard site PPE and equipment)</b>	<b>Atmospheric monitoring required?</b>
Ferrous Sulphate Heptahydrate	Frequent		No. Exposure duration is too short to present a respiratory hazard
Aluminium Sulphate	Frequent		No. Exposure duration is too short to present a respiratory hazard
Hydrogen Sulphide	Daily or when required	Evacuation procedures.	No. Exposure is limited due to the controls used, and high exposures are too unpredictable to monitor.
Polyacrylic Acid (Alcotac CB8)	Daily exposures when filling hopper that feeds mill.  3/week when mixing nucleation catalyst		No. Inhalation risk is not significant due to low vapour pressure

<b>Chemical</b>	<b>Frequency of exposure</b>	<b>Existing exposure controls (in addition to standard site PPE and equipment)</b>	<b>Atmospheric monitoring required?</b>
Perflo AP20 (Perlite)	2-3/week		No. Proportion of crystalline silica is extremely low, and the exposure duration is short
Hydrogen	Infrequent	Evacuation procedures	No. Exposures would be accidental and unpredictable
Nitrogen	Infrequent	Evacuation procedures	No. Exposures would be accidental and unpredictable
Nickel Sulphate	Infrequent		No. Not an inhalation hazard as it is present in solution
Anhydrous Ammonia	Depends upon number of truck deliveries	Full face respirator and protective suit  Evacuation procedures	Yes. Include for 5900 Operators to identify high exposure tasks
Magnafloc E10	Daily or weekly depending upon task		No. Inhalation exposures are not significant

<b>Chemical</b>	<b>Frequency of exposure</b>	<b>Existing exposure controls (in addition to standard site PPE and equipment)</b>	<b>Atmospheric monitoring required?</b>
Sodium Hydroxide (50%)	3/week	Procedures	No. Not present as a mist, therefore no inhalation hazard is present
Sodium Cyanide	3/week	Procedures  Appropriate respiratory protection must be worn	No. Exposures are brief and controlled via PPE
Sodium Sulphide	3/week	Procedures  Appropriate respiratory protection must be worn	No. Exposures are brief and controlled via PPE
Ammonium Sulphate	Daily		Yes. This is a simple addition to monitoring program. Monitor for inhalable dust and analyse samples for sulphur

<b>Chemical</b>	<b>Frequency of exposure</b>	<b>Existing exposure controls (in addition to standard site PPE and equipment)</b>	<b>Atmospheric monitoring required?</b>
Mixed Sulphides	Production dependant	Respiratory protection must be worn when bagging this material	Yes. Material is present on ground and can be made airborne by wind. Monitor for inhalable dust and analyse samples for nickel and cobalt.
Copper Cake	Daily		Yes. Will be included in program as it contains nickel and cobalt which both have carcinogenicity classifications. Monitor for inhalable dust and analyse samples for nickel and cobalt

<b>Chemical</b>	<b>Frequency of exposure</b>	<b>Existing exposure controls (in addition to standard site PPE and equipment)</b>	<b>Atmospheric monitoring required?</b>
Iron Cake	Daily		Yes. Will be included in program as it contains nickel and cobalt which both have carcinogenicity classifications. Monitor for inhalable dust and analyse samples for nickel and cobalt
Cobalt Powder	Daily	Respiratory protection is mandatory when working in the 3800 Packaging Shed	Yes. Cobalt has a carcinogenicity classification. Monitor for inhalable dust and analyse samples for cobalt
Cobalt Briquettes	Daily		No. Not an inhalation hazard



<b>Chemical</b>	<b>Frequency of exposure</b>	<b>Existing exposure controls (in addition to standard site PPE and equipment)</b>	<b>Atmospheric monitoring required?</b>
Shellsol 2046	Daily		Yes. Solvent exposures need to be assessed as both chronic and acute effects are possible. Analyse samples for total VOC (Volatile Organic Compounds) and its individual constituents including naphthalene
Cyanex 272 Extractant	Daily		No. Not an inhalation hazard as it is used in small concentrations and has a low vapour pressure.
Tributyl Phosphate	Daily		No. Not present in great enough concentrations for inhalation exposures to be of concern

<b>Chemical</b>	<b>Frequency of exposure</b>	<b>Existing exposure controls (in addition to standard site PPE and equipment)</b>	<b>Atmospheric monitoring required?</b>
Butylated Hydroxy Toluene (BHT)	Daily		No. Not present in great enough concentrations for inhalation exposures to be of concern
Sulphuric Acid (120g/L)	1/week when pouring and daily for taking samples		No. Acid is not present as a mist so there is no inhalation hazard
Sulphuric Acid (180g/L)	Daily		No. Acid is not present as a mist so there is no inhalation hazard
Dilute Aqueous Ammonia (67g/L)	Daily		No. Ammonia is in solution at a relatively low concentration so there is no inhalation hazard
Zinc Sulphate	Daily		No. Material is in solution so no inhalation hazard exists

<b>Chemical</b>	<b>Frequency of exposure</b>	<b>Existing exposure controls (in addition to standard site PPE and equipment)</b>	<b>Atmospheric monitoring required?</b>
Cobalt Sulphate	Daily		No. Material is in solution so no inhalation hazard exists
Hydrogen Peroxide	Unpredictable		No. Exposures are accidental and unpredictable
Ammonia	Unpredictable		<p>Yes. 5900 operators are already been monitored for this when unloading anhydrous ammonia delivery trucks.</p> <p>Do not include 3500 and 3600 operators in program as their exposures would be accidental and unpredictable</p>

<b>Chemical</b>	<b>Frequency of exposure</b>	<b>Existing exposure controls (in addition to standard site PPE and equipment)</b>	<b>Atmospheric monitoring required?</b>
Sulphur Dioxide	Every transfer of ammonia	Full face respirator, chemical suit and rubber gloves must be worn during transfer	No. Adequate controls are in place due to presence of ammonia, and high exposures would be accidental and unpredictable
Ferric Sulphate	Unpredictable		No. Product comes mixed with water so there is no inhalation hazard
Natural Gas	Unpredictable		No. Exposures would be accidental and unpredictable

<b>Chemical</b>	<b>Frequency of exposure</b>	<b>Existing exposure controls (in addition to standard site PPE and equipment)</b>	<b>Atmospheric monitoring required?</b>
General dust blowing throughout the Refinery	Daily		Yes. Will be included in program as it may contain nickel and cobalt which both have carcinogenicity classifications. Monitor for inhalable dust and analyse samples for nickel and cobalt

*Note*, standard site PPE includes long sleeved shirt, trousers, steel capped boots, safety glasses or monogoggles, half-face respirator, hydrogen sulphide gas monitor and hard hat. Standard site equipment includes safety shower / eye wash stations and local area gas detectors and alarms

Tables 11, 12 and 13 below provide a summary of the atmospheric contaminants which were included in the monitoring program, as well as an indication as to whether they had been included in previous programs. The following outlines these chemicals.

Table 11

*Chemicals Identified in Utilities for which Atmospheric Monitoring is Required*

<b>Operator</b>	<b>Atmospheric Contaminant</b>	<b>Included in Previous Monitoring Programs?</b>
4100/5100	Hydrogen Sulphide	Yes
	Sulphur Dioxide	No
	Respirable Dust – total and crystalline silica (quartz and cristobalite)	Yes
	Inhalable Dust – total, lime and sulphur	Yes
	Sulphuric Acid Mist	No

Table 12

*Chemicals Identified in Ore Leach for which Atmospheric Monitoring is Required*

<b>Operator</b>	<b>Atmospheric Contaminant</b>	<b>Included in Previous Monitoring Programs?</b>
3100	Inhalable Dust – total, nickel, cobalt, sulphur, copper, mercury chromium, arsenic, iron, zinc	No
	Sulphuric Acid Mist	No
3200	Inhalable Dust – total, nickel, cobalt, copper, mercury, chromium, arsenic, zinc	Yes
	Sulphuric Acid Mist	No
3300	Inhalable Dust – total, nickel, cobalt, calcium, copper, mercury chromium, arsenic, zinc	No
	Sulphuric Acid Mist	Yes
3400/3510	Inhalable Dust – total, nickel, cobalt, calcium, copper, mercury chromium, arsenic, zinc	No
	Sulphuric Acid Mist	No
	Hydrogen Sulphide	No

*Note*, Heavy metals were selected in accordance with the results presented in an internal monitoring report (Wing, 2003).

Table 13

*Chemicals Identified in Refinery for which Atmospheric Monitoring is Required*

<b>Operator</b>	<b>Atmospheric Contaminant</b>	<b>Included in Previous Monitoring Programs?</b>
3500	Inhalable Dust – total, nickel and cobalt	Yes
3600	Inhalable Dust – total, nickel and cobalt	Yes
3700	Inhalable Dust – total and nickel	Yes
3700 Furnace	Inhalable Dust – total and nickel	Yes
3800	Inhalable Dust – total and cobalt	Yes
Packager	Inhalable Dust – total, nickel and cobalt	Yes
3900	Inhalable Dust – total, nickel and cobalt	Yes
3900	Volatile Organic Compounds (VOC) – total VOC, C6-C9, C10-C14, benzene, toluene, ethyl benzene and xylene	Yes
5900	Inhalable Dust – total and ammonium sulphate	No
5900	Ammonia	No

**Hypothesis Part 3 - The implementation of a comprehensive hazard identification and monitoring program, would greatly improve capacity to quantify health risks of exposed workers.**

As outlined earlier, the sample results were analysed using the statistical package produced by the American Industrial Hygiene Association (Mulhausen & Damiano, 1998). A summary of these results is provided in the tables below. Appendices B, C and D contain a full listing of the results.



Table 14

*Statistical Summary of Results of Inhalable Dust, Respirable Dust and Sulphuric Acid Mist Monitoring Conducted in Utilities*

	<b>4100 / 5100 Operator inhalable dust</b>	<b>4100 /5100 Operator respirable dust</b>	<b>4100 /5100 Operator sulphuric acid mist</b>
<b>Exposure Standard (mg/m<sup>3</sup>)</b>	9	4.5	0.5
<b>Number of Samples</b>	7	7	6
<b>Distribution Type</b>	Log-normal	None	None
<b>Range of Results (mg/m<sup>3</sup>)</b>	0.7 to 1.7	<0.1 to 0.7	All results <0.05
<b>Arithmetic Mean (mg/m<sup>3</sup>)</b>	1.2	0.2	<0.05
<b>95% UCL Mean (mg/m<sup>3</sup>)</b>	1.6	-	-
<b>Geometric Standard Deviation</b>	1.4	2.4	1
<b>% Exceedance</b>	<0.001	0	0

*Note, 95% UCL Mean = Arithmetic Mean's One Sided 95% Upper Confidence Limit*

As indicated earlier in this chapter, all inhalable dust samples were analysed for sulphur and lime, while all respirable dust samples were analysed for quartz and cristobalite. In all cases the concentrations of these additional analytes were either negligible or below the limit of detection. As a result, the exact concentrations are not included in this summary. Appendices B, C and D contain a full listing of the results.

### **Utilities – Hydrogen Sulphide (Area 4100/5100 Operator)**

All TWA exposures were less than 1 ppm (TWA = 5 ppm).

STEL exposures varied from less than 1 ppm to a maximum of 2 ppm (STEL = 15 ppm) indicating that the STEL exposure standard was never exceeded.

According to Rappaport (Rappaport et al., 1988), it can be predicted that if the arithmetic mean exposure for a full shift is kept below 1 ppm, then the proportion of STEL results exceeding the exposure standard will be no more than 1.5%.

Tasks which exposed employees to instantaneous concentrations above the TWA exposure standard:

- Adding diatomaceous earth to the pre-coat pit in Area 4100; and
- Draining the blowdown vessel in Area 5100; and
- Process leaks also have the potential to create high exposures.

### **Utilities – Sulphur Dioxide (Area 4100/5100 Operator)**

All TWA exposures were less than 0.1 ppm (TWA = 1 ppm).

STEL exposures varied from less than 0.1 ppm to a maximum of 1.5 ppm (STEL = 5 ppm) indicating that the STEL exposure standard was never exceeded.

According to Rappaport (Rappaport et al., 1988), it can be predicted that if the arithmetic mean exposure for a full shift is kept below 0.1 ppm, then the proportion of STEL results exceeding the exposure standard will be no more than 1.5%.

Tasks which exposed employees to instantaneous concentrations above the TWA exposure standard:

- Emptying out condensed sulphuric acid from cold interpass knock out pot; and
- Adding diatomaceous earth to the pre-coat pit in Area 4100; and
- Cleaning sulphur filters; and
- Process leaks also have the potential to create high exposures.

Table 15

*Statistical Summary of Results of Inhalable Dust Monitoring Conducted in Ore Leach*

	<b>3100 Operator</b>	<b>3200 Operator</b>	<b>3300 Operator</b>	<b>3400/3510 Operator</b>
<b>Exposure Standard (mg/m<sup>3</sup>)</b>	9	9	9	9
<b>Number of Samples</b>	6	6	7	6
<b>Distribution Type</b>	Log-normal	Log-normal	Log-normal	Normal
<b>Range of Results (mg/m<sup>3</sup>)</b>	0.5 to 9.3	0.2 to 0.8	<0.1 to 0.8	<0.1 to 0.9
<b>Arithmetic Mean (mg/m<sup>3</sup>)</b>	3.9	0.5	0.4	0.6
<b>95% UCL Mean (mg/m<sup>3</sup>)</b>	69	0.9	1.7	0.9
<b>Geometric Standard Deviation</b>	3.4	1.6	2.7	2.7
<b>% Exceedance</b>	12	<0.001	0.01	<0.001

As indicated earlier in this chapter, all inhalable dust samples were analysed for a wide variety of metals depending upon the process area relevant to the sample. In all cases the concentrations of these additional analytes were either negligible or below the limit of detection. As a result, the exact concentrations are not included in this summary. Appendices B, C and D contain a full listing of the results.

Table 16

*Statistical Summary of Results of Sulphuric Acid Mist Monitoring Conducted in Ore Leach*

	<b>3100 Operator</b>	<b>3200 Operator</b>	<b>3300 Operator</b>	<b>3400/3510 Operator</b>
<b>Exposure Standard (mg/m<sup>3</sup>)</b>	0.5	0.5	0.5	0.5
<b>Number of Samples</b>	6	6	6	6
<b>Distribution Type</b>	None	None	None	None
<b>Range of Results (mg/m<sup>3</sup>)</b>	<0.05 to 0.15	<0.05 to 0.17	<0.05 to 0.2	<0.05 to 0.1
<b>Arithmetic Mean (mg/m<sup>3</sup>)</b>	0.07	0.06	0.07	0.05
<b>95% UCL Mean (mg/m<sup>3</sup>)</b>	-	-	-	-
<b>Geometric Standard Deviation</b>	1.9	1.9	2.0	1.5
<b>% Exceedance</b>	0	0	0	0

**Ore Leach – Hydrogen Sulphide (3400/3510 Operator)**

All TWA exposures were less than 1 ppm (TWA = 5 ppm).

All STEL exposures were less than 1 ppm (STEL = 15 ppm) indicating that the STEL exposure standard was never exceeded. According to Rappaport (Rappaport et al., 1988), it can be predicted that if the arithmetic mean exposure for a

full shift is kept below 1 ppm, then the proportion of STEL results exceeding the exposure standard will be no more than 1.5%.

No tasks which expose employees to instantaneous concentrations above the TWA exposure standard were identified.

Process leaks also have the potential to create high exposures.

## Refinery – Inhalable Dust

Table 17a

*Statistical Summary of Results of Inhalable Dust Monitoring Conducted in Refinery*

	<b>3500 Operator</b>	<b>3600 Operator</b>	<b>3700 Operator</b>	<b>3700 Furnace Operator</b>
<b>Number of Samples</b>	19	18	18	22
<b>Exposure Standard (mg/m<sup>3</sup>)</b>	9	9	9	9
<b>Distribution Type</b>	Log- normal	None	Log- normal	Log- normal
<b>Range of Results (mg/m<sup>3</sup>)</b>	0.3 to 5.2	<0.01 to 3.4	0.2 to 2.2	0.4 to 5.7
<b>Arithmetic Mean (mg/m<sup>3</sup>)</b>	1.0	0.8	0.8	1.3
<b>95% UCL Mean (mg/m<sup>3</sup>)</b>	1.4	-	1.1	1.8
<b>Geometric Standard Deviation</b>	2.1	4.2	1.8	1.8
<b>% Exceedance</b>	0.03	0	0.001	0.04

Table 17b

*Statistical Summary of Results of Inhalable Dust Monitoring Conducted in Refinery*  
(continued)

	<b>Packaging operator</b>	<b>3800 Operator</b>	<b>3900 Operator</b>	<b>5900 Operator</b>
<b>Number of Samples</b>	22	20	21	6
<b>Exposure Standard (mg/m<sup>3</sup>)</b>	9	9	9	9
<b>Distribution Type</b>	Normal	Log- normal	Log- normal	Log- normal
<b>Range of Results (mg/m<sup>3</sup>)</b>	0.1 to 2	0.2 to 1.6	0.1 to 1	0.2 to 0.9
<b>Arithmetic Mean (mg/m<sup>3</sup>)</b>	0.8	0.7	0.4	0.5
<b>95% UCL Mean (mg/m<sup>3</sup>)</b>	1.0	1.0	0.6	1.1
<b>Geometric Standard Deviation</b>	1.9	1.9	1.9	1.9
<b>% Exceedance</b>	<0.001	0.001	<0.001	<0.001

Table 18

*Statistical Summary of Results of Nickel Dust Monitoring Conducted in Refinery*

	<b>3500 Operator</b>	<b>3600 Operator</b>	<b>3700 Operator</b>	<b>3700 Furnace operator</b>	<b>Packaging operator</b>	<b>3900 Operator</b>
<b>Number of Samples</b>	19	18	18	22	22	21
<b>Exposure Standard (mg/m<sup>3</sup>)</b>	0.9	0.9	0.9	0.9	0.9	0.9
<b>Distribution Type</b>	Log- normal	Log- normal	Log- normal	Log- normal	Log-normal	None
<b>Range of Results (mg/m<sup>3</sup>)</b>	0.03 to 1.6	<0.01 to 0.32	0.02 to 0.38	0.06 to 3.3	0.03 to 1.1	<0.01 to 0.07
<b>Arithmetic Mean (mg/m<sup>3</sup>)</b>	0.20	0.04	0.12	0.58	0.23	0.02
<b>95% UCL Mean (mg/m<sup>3</sup>)</b>	0.44	0.1	0.22	0.95	0.38	-
<b>Geometric Standard Deviation</b>	3.1	2.9	2.5	2.5	2.5	2.2
<b>% Exceedance</b>	3.2	0.03	0.5	18	2.8	0



Table 19

*Statistical Summary of Results of Cobalt Dust Monitoring Conducted in Refinery*

	<b>3500 Operator</b>	<b>3600 Operator</b>	<b>Packaging operator</b>	<b>3800 Operator</b>	<b>3900 Operator</b>
<b>Number of Samples</b>	19	18	22	20	21
<b>Exposure Standard (mg/m<sup>3</sup>)</b>	0.05	0.05	0.05	0.05	0.05
<b>Distribution Type</b>	None	None	None	Log- normal	None
<b>Range of Results (mg/m<sup>3</sup>)</b>	<0.01 to 0.12	<0.01 to 0.03	<0.01 to 0.34	<0.01 to 0.52	<0.01 to 0.03
<b>Arithmetic Mean (mg/m<sup>3</sup>)</b>	0.02	0.01	0.04	0.14	0.01
<b>95% UCL Mean (mg/m<sup>3</sup>)</b>	-	-	-	0.47	-
<b>Geometric Standard Deviation</b>	2.2	1.4	3.8	4.5	1.5
<b>% Exceedance</b>	4.9	0	14	49	0

## Refinery – Ammonia (5900 Operator)

Table 20

*Statistical Summary of Results of Ammonia Monitoring Conducted in Refinery*

<b>5900 Operator</b>	
<b>Number of Samples</b>	6
<b>Exposure Standard (ppm)</b>	13
<b>Distribution Type</b>	Log-normal
<b>Range of Results (ppm)</b>	3 to 7
<b>Arithmetic Mean (ppm)</b>	4.8
<b>95% UCL Mean (ppm)</b>	7.3
<b>Geometric Standard Deviation</b>	1.5
<b>% Exceedance</b>	0.3

*Note* – These statistical analyses are normally not valid for contaminants which do not cause long term health effects, as is the case for ammonia. However, it has been included here because a TWA exposure standard was recommended by the ACGIH (American Conference of Governmental Industrial Hygienists, 2002) in order to increase protection for workers who have not built up a resistance to the effects of ammonia. Such analyses were not completed earlier for sulphur dioxide and hydrogen sulphide as nearly all results were below the limit of detection.

STEL exposures varied from 5 ppm to a maximum of 17 ppm (STEL = 35 ppm) indicating that the STEL exposure standard was never exceeded. According to Rappaport (Rappaport et al., 1988), it can be predicted that if the arithmetic mean exposure for a full shift is kept below 4.8 ppm, then the proportion of STEL results exceeding the exposure standard will be no more than 3%.

Tasks which exposed employees to instantaneous concentrations above the TWA exposure standard:

- Any task involving the release of ammoniated water; and
- Unloading ammonia from truck to storage tanks; and

- Sampling Tank 12; and
- Process leaks also have the potential to create high exposures.

### **Refinery – Solvents (3900 Operator)**

Table 21

*Statistical Summary of Results of Solvent Monitoring (Total VOC) Conducted in Refinery*

<b>3900 Operator</b>	
<b>Number of Samples</b>	6
<b>Exposure Standard (mg/m<sup>3</sup>)</b>	175
<b>Distribution Type</b>	Log-normal
<b>Range of Results (mg/m<sup>3</sup>)</b>	<0.1 to 20
<b>Arithmetic Mean (mg/m<sup>3</sup>)</b>	3.5
<b>95% UCL Mean (mg/m<sup>3</sup>)</b>	413769
<b>Geometric Standard Deviation</b>	12
<b>% Exceedance</b>	0.9

*Note*, VOC = Volatile Organic Compounds

Extremely small concentrations of toluene and naphthalene were also detected. These concentrations were found to be so far below the exposure standards as to be insignificant.

Tables 19 to 21 below use the equation outlined in Chapter 3 to predict the potential chronic health effects of the combination of contaminants which operators are exposed to. Only TWA exposure results are included.

Table 22

*Total Additive Exposures for Operators Working in Utilities*

<b>Operator type</b>	<b>Respirable dust (mg/m<sup>3</sup>)</b>	<b>Inhalable dust (mg/m<sup>3</sup>)</b>	<b>Sulphuric acid mist (mg/m<sup>3</sup>)</b>	<b>Sulphur dioxide (ppm)</b>	<b>Hydrogen sulphide (ppm)</b>	<b>Total additive exposure</b>
4100/5100	0.2	1.2	<0.05	<0.1	<1	<b>0.18</b>
Exposure Standard	4.5	9	0.5	1	5	<b>1</b>

*Note.* In calculating additive results, figures which were less than the detection limit were not included, as doing so would have the effect of increasing the overall result even though the atmospheric contaminant had not been proved to be present.

Table 23

*Total Additive Exposures for Operators Working in Ore Leach*

<b>Operator type</b>	<b>Inhalable dust (mg/m<sup>3</sup>)</b>	<b>Sulphuric acid mist (mg/m<sup>3</sup>)</b>	<b>Hydrogen sulphide (ppm)</b>	<b>Total additive exposure</b>
3100	3.9	0.07		<b>0.57</b>
3200	0.5	0.06		<b>0.18</b>
3300	0.4	0.07		<b>0.18</b>
3400/3510	0.6	0.05	<1	<b>0.17</b>
Exposure Standard	9 mg/m <sup>3</sup>	0.5 mg/m <sup>3</sup>	5 ppm	<b>1</b>

*Note.* In calculating additive results, figures which were less than the detection limit were not included, as doing so would have the effect of increasing the overall result even though the atmospheric contaminant had not been proved to be present.

Table 24

*Total Additive Exposures for Operators Working in Refinery*

<b>Operator type</b>	<b>Inhalable dust (mg/m<sup>3</sup>)</b>	<b>Nickel (mg/m<sup>3</sup>)</b>	<b>Cobalt (mg/m<sup>3</sup>)</b>	<b>Total VOC (mg/m<sup>3</sup>)</b>	<b>Ammonia (ppm)</b>	<b>Total additive exposure</b>
3500	1.0	0.2	0.02			<b>0.73</b>
3600	0.8	0.04	0.01			<b>0.33</b>
3700	0.8	0.12				<b>0.22</b>
3700 Furnace	1.3	0.58				<b>0.79</b>
Packager	0.8	0.23	0.04			<b>1.14</b>
3800	0.7		0.14			<b>2.88</b>
3900	0.4	0.02	0.01	3.5		<b>0.29</b>
5900	0.5				4.8	<b>0.42</b>
Exposure Standard	9	0.9	0.05	175	13	<b>1</b>

As can be seen, a significant amount of information has been gathered in order to test the three hypotheses. This information commenced with a listing of all potential chemical hazards followed by a basic assessment to determine if monitoring was required. The newly identified monitoring requirements then compared with historical monitoring activities, and a summary of the subsequent monitoring results was provided. Most of this information is new to Minara Resources and will now provide the basis for an in depth analysis of the potential for workers to suffer adverse health effects.

## **CHAPTER 5 – DISCUSSION AND CONCLUSIONS**

The chapter discusses the meaning of the results in the context of the three hypotheses'. The aim is to determine the success of this study in meeting its objectives.

### **Hypothesis Part 1 - Chemical Hazards at Murrin Murrin Have Not Been Adequately Identified**

A full identification of all chemical hazards on site had never been completed prior to this study. As a result, a hazardous substances register, as required by law, had never been produced.

The results of this study relating to this hypothesis can now be used to produce such a register for production based work.

This register will need to be maintained to ensure that it remains relevant. To do this will require the implementation of a rigorous program of chemical screening prior to any material being brought onto site.

This assessment process will enable the early identification of potential health hazards. Materials can then either be banned from site or monitoring, assessment and exposure control programs can be implemented to ensure the protection of worker health.

This process of assessment would represent a critical change to the management of occupational hygiene issues. Instead of being reactive to the concerns of employees, the company will be able to provide employees with the necessary information before they commence using any product. This will reduce the potential for industrial unrest within the workforce, and by virtue of increased regulatory compliance, will reduce the potential for negative action to be taken by regulatory bodies.

## **Hypothesis Part 2 - The current occupational hygiene monitoring protocols do not adequately quantify worker exposures to these chemical hazards**

Without a complete understanding of the chemical hazards present, it was highly unlikely that the historical monitoring programs would be complete.

As shown in Tables 8 -10, several new items were included in the monitoring program. In some cases, the results of this monitoring showed that there was little risk. However this information is just as valuable in eliminating areas of concern, as it can be presented to employees to provide them with a greater understanding of their exposures.

Having this complete picture of exposures enabled the analysis of potential additive effects of several chemical exposures acting together in the body. Such an analysis has never been possible in the past.

The manner in which the samples were taken was also much improved. Hazards with the potential for long-term health effects were assessed via random monitoring which eliminates biases which can be built into non-random programs. This is much more acceptable from an epidemiological perspective so the results may be useful for future research.

## **Hypothesis Part 3 - The implementation of a comprehensive hazard identification and monitoring program, will greatly improve capacity to quantify health risks of exposed workers.**

This section brings together all of the results and a complete analysis of the potential for adverse health effects in operators will be provided.

Before commencing with this analysis, it is necessary to provide a full explanation of the exposure standards used, as these provide the basis for health related assessments.

As was outlined in Chapter 2, TWA exposure standards refer to “the average airborne concentration of a particular substance when calculated over a normal eight-hour working day, for a five-day working week” (National Occupational Health and Safety Commission, 1995a, p. 70). At Murrin Murrin, the individuals involved in

this study worked a fly in/fly out roster consisting of 14 twelve hour shifts in each four week period.

This differing work schedule means that they are spending a greater number of hours at work which has implications for the exposure standard. NOHSC has recognised this and have stated that “where workers have a working day longer than eight hours or unusual shift rotations are in effect, the TWA exposure standard may need to be reduced by a suitable factor to ensure adequate worker protection” (National Occupational Health and Safety Commission, 1995a, p. 9). This is based upon the fact that extra hours mean that a worker is exposed for longer periods of time and also has a reduced period of time between shifts to recover.

NOHSC has provided general guidance on three of the main models used to adjust exposure standards for extended work shifts (National Occupational Health and Safety Commission, 1995a). These models are:

1. Brief and Scala – this model uses a simple mathematical formula to adjust exposure standards based upon the number of hours worked per 24 hour day and the period of time between exposures. It recognises that extended work shifts can not only lead to extended periods of exposure, but that they also lead to a reduction in the time available for the body to eliminate the contaminant between shifts. The formula used is as follows:

$$\text{Adjusted ES} = 8 * (24-h) * \text{ES (8 hour TWA)} / 16 * h$$

Where ES = Exposure Standard and h = hours worked per 24 hours

Under this model, it is recommended that the exposure standards for 12 hour shifts, as worked at Murrin Murrin, be halved.

2. OSHA – this model is used in the United States by the Occupational Health and Safety Administration. Under this model, contaminants are categorised into one of six categories depending upon the toxic effects which are present. Each one of these categories then has a specific method to adjust the exposure standard. This model is not recommended for use in Australia due to this categorisation system and the exposure standards in use.



3. Pharmacokinetic (of Hickey and Reist) – this model uses a knowledge of the behaviour of the contaminant in the body to recommend exposure standard reductions. It relies upon the substances biological half life, and while this model is theoretically more accurate than simpler methods, it tends to be the most conservative (i.e. it leads to the smallest exposure standard reduction of the three methods discussed). This model is generally not recommended because this “lack of conservatism may not allow adequately for the unknown adverse effects on the body from nightwork or extended shifts that might effect how well the body metabolises and eliminates the substance” (National Occupational Health and Safety Commission, 1995b).

Although the Brief and Scala model is the preferred model recommend by NOHSC, in Western Australia DOCEP has provided additional guidance on how to calculate this adjustment (Department of Industry and Resources, 1999). This additional guidance is based upon the assertion that “while use of the Brief and Scala model may be appropriate for some substances, particularly substances that cause short-term respiratory irritation or narcosis, it is not appropriate for many of the metals and mineral dusts encountered in mining” (Department of Industry and Resources, 1999, p. 2).

Under the DOCEP model, exposure standards for contaminants with medium term health effects (i.e. within a shift or over a few shifts) are adjusted according to the Brief and Scala Model, whilst those with long term effects (i.e. over many shifts or years) are adjusted according to a formula based upon the average number of hours worked in a month. Additionally, STEL or Peak exposure standards for contaminants with immediate health effects are not adjusted.

Following the requirements of this guide, several of the exposure standards used in this study have been adjusted as follows:

Table 25

*Exposure Standard Adjustments used in this Study*

<b>Atmospheric Contaminant</b>	<b>TWA Exposure Standard (unadjusted)</b>	<b>TWA Exposure Standard (Adjusted)</b>	<b>STEL Exposure Standard (if applicable)</b>
Inhalable Dust	10 mg/m <sup>3</sup>	9 mg/m <sup>3</sup>	
Nickel	1 mg/m <sup>3</sup>	0.9 mg/m <sup>3</sup>	
Cobalt	0.05 mg/m <sup>3</sup>	0.05 mg/m <sup>3</sup>	
Respirable Dust	5 mg/m <sup>3</sup>	4.5 mg/m <sup>3</sup>	
Respirable Quartz	0.2 mg/m <sup>3</sup>	0.18 mg/m <sup>3</sup>	
Sulphuric Acid Mist	1 mg/m <sup>3</sup>	0.5 mg/m <sup>3</sup>	3 mg/m <sup>3</sup>
Hydrogen Sulphide	10 ppm	5 ppm	15 ppm
Sulphur Dioxide	2 ppm	1 ppm	5 ppm
Ammonia	25 ppm	13 ppm	35 ppm
Total VOC	350 mg/m <sup>3</sup> <sup>a</sup>	175 mg/m <sup>3</sup>	

*Note*, All unadjusted TWA exposure standards and STEL's were sourced from NOHSC (National Occupational Health and Safety Commission, 1995a).

<sup>a</sup> The Total VOC standard is a manufacturer recommendation sourced from their MSDS.

STEL standards were not adjusted as these apply to acute health effects which can occur once a certain atmospheric concentration is reached.

### **Utilities – 4100/5100 Operators**

Area 4100/5100 operators within Utilities were monitored for hydrogen sulphide and sulphur dioxide gases, and both inhalable and respirable dust. The inhalable dust samples were then further analysed for sulphur and lime, whilst the respirable dust samples were analysed for quartz and cristobalite.

Seven inhalable dust results for 4100/5100 operators were taken during the monitoring program. From the statistical summary provided in Table 14, the following points can be made:

1. None of these results exceeded the exposure standard of  $9 \text{ mg/m}^3$  and the arithmetic mean exposure was calculated to be  $1.2 \text{ mg/m}^3$ .
2. The arithmetic mean's one sided 95% upper confidence limit of  $1.6 \text{ mg/m}^3$  is also well below the exposure standard. From these results we can be 95% confident that the true arithmetic mean of the exposure profile is less than the exposure standard.
3. The samples were found to have a GSD (Geometric Standard Deviation) well below the recommended value of 3 (European Committee for Standardization, 1995) indicating that there is a low level of variability in the exposures. This indicates that the SEG is appropriate and does not require further differentiation.
4. The predicted exposure standard exceedance percentage of  $<0.001\%$  indicates an extremely high level of compliance with the exposure standard.
5. Concentrations of lime and sulphur detected in each of the samples were either negligible or below the limit of detection.

**From the analysis presented above, it can be inferred that the exposures of 4100/5100 operators to inhalable dust and its potential contents (lime and sulphur) are acceptable.**

Seven respirable dust results for 4100/5100 operators were taken during the monitoring program. From the statistical summary provided in Table 14, the following can points can be made:

1. None of these results exceeded the exposure standard of  $4.5 \text{ mg/m}^3$  and the arithmetic mean exposure was calculated to be  $0.2 \text{ mg/m}^3$ .
2. The arithmetic mean's one sided 95% upper confidence limit and the predicted exposure standard exceedance could not be calculated as the exposure distribution could not be classified as either normal or lognormal. As a result only descriptive statistics could be used.

3. The samples were found to have a GSD (Geometric Standard Deviation) below the recommended value of 3 (European Committee for Standardization, 1995) indicating that there is a low level of variability in the exposures. Thus the SEG is appropriate and does not require further differentiation.
4. Four of the seven samples returned results which were less than the limit of detection.
5. Concentrations of quartz and cristobalite detected in each of the samples were either negligible or below the limit of detection.

**From the analysis presented above, it can be inferred that the exposures of 4100/5100 operators to respirable dust and its potential contents (quartz and cristobalite) are acceptable.**

All measured exposures to sulphuric acid mist were found to be below the limit of detection, and therefore well below the exposure standard. In retrospect it is concluded that random sampling for this contaminant is inappropriate, as high exposures may only occur if operators were working near a leak in the process. If this were to be the case, then protective measures such as the use of respiratory protection would be required immediately. It is worth noting that sulphuric acid mists are visible to the naked eye, so the identification of leaks prior to an exposure is possible.

**From the analysis presented above, it can be inferred that the exposures of 4100/5100 operators to sulphuric acid mist are acceptable under normal production conditions. However, if there are problems with the process and mist is released from the system, then exposure control measures would be required.**

As was the case for sulphuric acid mists, it was found that random sampling for hydrogen sulphide and sulphur dioxide gases was inappropriate as TWA exposures were found on all occasions to be less than the detection limit. The risk with both of these gases is the possibility of accidental short term, high concentration exposures. As was discussed in Chapter 3, these situations are best assessed using data logging instruments to record the fluctuation of exposures over the work shift. By using this methodology, several high exposure tasks were identified. These tasks

are listed in Chapter 4 and the operators are aware of them. This awareness allows them to take protective measures, predominantly the use of respiratory protection which is carried at all times, to reduce these exposures. In the case of hydrogen sulphide, area alarm systems are present in high risk areas such as around the Hydrogen Sulphide Plant (Area 5100). When high concentrations are detected, these alarms sound and anybody in the area is required to don their respirator and evacuate. This requirement is supported by training carried out during the induction process.

**From the analysis presented above, it can be inferred that the exposures of 4100/5100 operators to hydrogen sulphide and sulphur dioxide are acceptable under normal production conditions. However, during certain tasks, or if there are problems with the process and either gas is released from the system, then exposure control measures would be required.**

The additive effect of exposure of 4100/5100 operators to all of the contaminants discussed above was calculated to be 0.18 (see Table 22) which is well below the acceptable standard of 1. **The major health risk to these operators is therefore exposures to high concentrations of contaminants during production problems, or whilst carrying out certain tasks.**

### **Ore Leach – 3100 Operators**

3100 operators were sampled for inhalable dust and sulphuric acid mist. The inhalable dust samples were further analysed for several specific metals as outlined in Table 9 of Chapter 3.

Six inhalable dust samples were taken, and from the statistical summary provided in Table 15, the following points can be made:

1. One sample exceeded the exposure standard of  $9 \text{ mg/m}^3$ .
2. The arithmetic mean was calculated to be 3.9, and due to high exposure variability, the 95% upper confidence limit of this mean was well above the exposure standard. Therefore we can not conclude with 95% confidence that the arithmetic mean for all exposures is less than the exposure standard.
3. As stated above, there was a high degree of exposure variability as the GSD was greater than 3. In order to determine the source of this variability the Monitoring Logsheets were examined and the operator whose result exceeded

the exposure standard was interviewed. From this it was concluded that operator exposures are heavily influenced by the amount of time spent on one task, namely hosing out the sizer tunnel. On the day of the exposure standard exceedance, the operator stated that he spent more time than usual carrying out this task.

4. The predicted percentage of samples above the exposure standard was also found to be much greater than 5, which indicates that exposure standard exceedances occur on a regular basis.
5. The concentrations of all of the metals analysed in each sample were either negligible or below the limit of detection.

**From the analysis presented above, it can be inferred that the exposure of 3100 operators to inhalable dust is unacceptable. This conclusion is due to one task which has the potential to greatly increase exposures when it is conducted. Control measures are therefore required when conducting this task. At present, this control is achieved via the use of respiratory protection.**

Six sulphuric acid mist samples were taken, and from the statistical summary provided in Table 16, the following points can be made:

1. Four of the six results were found to be below the detection limit, and the highest result of  $0.15 \text{ mg/m}^3$  was well below the exposure standard of  $0.5 \text{ mg/m}^3$ .
2. The mean exposure was found to be  $0.06 \text{ mg/m}^3$  which is well below the exposure standard.
3. The arithmetic mean's one sided 95% upper confidence limit and the predicted exposure standard exceedance could not be calculated as the exposure distribution could not be classified as either normal or lognormal. Therefore only descriptive statistics were used.
4. The GSD was found to be less than 3 indicating that there is an acceptable level of variability in this SEG.

**From the analysis presented above, it can be inferred that the exposure of 3100 operators to sulphuric acid mist is acceptable. With the information gathered it was not possible to determine what was different for the two samples**

**that recorded a concentration greater than the detection limit. Further monitoring may be useful to both identify this and to increase the confidence in this conclusion.**

The additive exposures of 3100 operators to both inhalable dust and sulphuric acid mist are slightly greater than half of the acceptable standard (see Table 23). This slightly elevated result is due to the concerns associated with inhalable dust exposures.

### **Ore Leach – 3200, 3300 and 3400/3510 Operators**

3200, 3300 and 3400/3510 operators were monitored for inhalable dust and sulphuric acid mists. The inhalable dust samples were then further analysed for several specific metals as outlined in Table 9 of Chapter 3.

At least six inhalable dust samples were taken for each operator group, and from the statistical summary provided in Table 15, the following points can be made:

1. No result was found to exceed the exposure standard
2. The estimated arithmetic means and one sided 95% upper confidence limits of these means for all three groups were well below the exposure standard of 9 mg/m<sup>3</sup>. It can therefore be inferred with 95% confidence that the true arithmetic mean of the exposure profiles is less than the exposure standard.
3. The predicted exposure standard exceedance percentages for all groups were well below the acceptable standard of 5%.
4. The GSD's for all groups were below 3 indicating acceptable levels of variability within each SEG.
5. The concentrations of all of the metals analysed for in each sample were either negligible or below the limit of detection.

**From the analysis presented above, it can be inferred that the exposures of 3200, 3300 and 3400/3510 operators to inhalable dust and its potential contents are acceptable.**

Six sulphuric acid mist samples were taken on 3200, 3300 and 3400/3510 operators, and from the statistical summary provided in Table 16, the following points can be made:

1. All results were well below the exposure standard of  $0.5 \text{ mg/m}^3$  for each grouping. The highest result was  $0.2 \text{ mg/m}^3$  recorded on a 3300 operator. Most results were found to be below the limit of detection.
2. Mean exposures were below the exposure standard for all groups.
3. The arithmetic mean's one sided 95% upper confidence limit and the predicted exposure standard exceedance could not be calculated as the exposure distribution could not be classified as either normal or lognormal. As a result only descriptive statistics could be used.
4. The GSD's for each group was found to be less than 3 indicating that there is an acceptable level of variability in this SEG.

**From the analysis presented above, it can be inferred that the exposures of 3200, 3300 and 3400/3510 operators to sulphuric acid mists is acceptable.**

Six samples were taken on 3400/3510 operators for hydrogen sulphide using data logging instrumentation. Five of the six samples did not record any hydrogen sulphide above the detection limit, whilst the sixth sample recorded a maximum of 1 ppm.

**From the analysis presented above, it can be inferred that the exposures of 3400/3510 operators to hydrogen sulphide is acceptable under normal production processes. As was the case for 4100/5100 operators in Utilities the most significant risk is exposure to high , short term concentrations which can occur if there is a leak or production problem. Protective measures in the form of respiratory protection and local area alarms are in place to prevent such exposures.**

The additive exposures of 3200, 3300 and 3400/3510 operators to inhalable dust, sulphuric acid mist and hydrogen sulphide (for 3400/3510 operators only) were all less than 20% of the acceptable standard (see Table 23).

### **Refinery – 3500 Operators**

19 inhalable dust samples were included in this study. The reason for this is that a random sampling program had been in place since November 2002, and the results were therefore compatible with this study. Each of these samples was further



analysed for nickel and cobalt. From these results, and the statistical summaries provided in Tables 17a, 18 and 19, the following points can be made:

1. All inhalable dust results were well below the exposure standard of  $9 \text{ mg/m}^3$ , with a maximum exposure of  $5.2 \text{ mg/m}^3$ . Both the arithmetic mean and mean's one sided 95% upper confidence limit were also well below the exposure standard. The GSD of 2.1 was below the acceptable limit of 3 indicating that there is an acceptable level of variability within these results.
2. One of the 19 results recorded a nickel exposure in excess of the exposure standard of  $0.9 \text{ mg/m}^3$ , and a cobalt result in excess of the exposure standard of  $0.05 \text{ mg/m}^3$ . For both metals these results were four times higher than the next highest result and were due to the specific task of cutting open bags of process scale so they could be emptied. This task released high levels of dust. Once this problem was recognised, the material in the bag was wetted and respiratory protection was worn to reduce exposure.
3. The estimated arithmetic means of  $0.2 \text{ mg/m}^3$  for nickel and  $0.02 \text{ mg/m}^3$  for cobalt were well below the applicable exposure standards.
4. The arithmetic mean's one sided 95% upper confidence limit for nickel was  $0.44 \text{ mg/m}^3$  which is also well below the standard. This value could not be calculated for the cobalt results as the exposures did not fit either a lognormal or normal exposure distribution.
5. The predicted exposure standard exceedances were 3.2% for nickel, while 5.2% of the results exceeded the cobalt exposure standard (this cobalt percentage is the actual percentage and not a predicted percentage. A predicted value could not be calculated as the results did not fit either a normal or lognormal exposure distribution). If the one elevated result discussed above is ignored, then these percentages drop even further.
6. Exposure variability was high (i.e. GSD greater than 3) for nickel and acceptable for cobalt. However this high variability within the nickel results was due to the one sample outlined above.

**From the analysis presented above, it can be inferred that the exposures of 3500 operators to inhalable dust, nickel and cobalt is acceptable under normal production activities. However, for certain tasks involving working**

**with dry production materials, it is possible to record highly elevated results in excess of the exposure standard. It is therefore necessary to implement exposure control measures prior to conducting such activities.**

The additive exposure of the above contaminants was calculated to be 0.73 against the standard of 1 (see Table 24). However, if the one high sample is removed from these results, the additive exposure value drops to 0.47 which is slightly less than half of the standard. This highlights the importance of information collected by the Monitoring Logsheets.

### **Refinery – 3600 Operators**

For the same reason as detailed for 3500 operators, more than six inhalable dust results are included in this study. Each of these samples was further analysed for nickel and cobalt. From these results, and the statistical summaries provided in Tables 17a, 18 and 19, the following points can be made:

1. All inhalable dust, nickel and cobalt results were below the relevant exposure standards.
2. The arithmetic means for inhalable dust, nickel and cobalt were all below the exposure standard. The arithmetic mean's one side 95% upper confidence limit was also below the exposure standard for nickel. Such a calculation could not be made for inhalable dust and cobalt as the exposures did not fit either a lognormal or normal distribution.
3. The predicted percentage of results exceeding the exposure standard was less than 5% for nickel. This calculation could not be made for inhalable dust and cobalt as these exposures did not fit either a lognormal or normal distribution.
4. GSD's were acceptable for nickel and cobalt, but above 3 for inhalable dust. In fact the GSD for inhalable dust was 4.2. The reasons for this high variability are not known, but it may be due to several extremely low results. 3600 is an area where dust is not highly visible and is unlikely to be generated in high concentrations. To identify the exact causes, it would be necessary to examine the work regime of 3600 operators in greater detail. However, due to the low results obtained, this activity is not warranted as the benefits would be minimal.

**From the analysis presented above, it can be inferred that the exposures of 3600 operators to inhalable dust, nickel and cobalt are acceptable.**

Additive exposures were also found to be well below the acceptable limit for 3600 operators (see Table 24).

#### **Refinery – 3700 Operators**

For the same reason as detailed for 3500 operators, more than six inhalable dust results are included in this study. Each of these samples was further analysed for nickel. From these results, and the statistical summaries provided in Tables 17a and 18, the following points can be made:

1. All inhalable dust and nickel results were below the relevant exposure standards.
2. The arithmetic means for inhalable dust and nickel were both below the exposure standard. The arithmetic mean's one side 95% upper confidence limit was also below the exposure standard for both inhalable dust and nickel.
3. The percentage of results exceeding the exposure standard was less than 5% for inhalable dust and nickel.
4. GSD's for both inhalable dust and nickel were below three indicating that the level of variability is acceptable.

**From the analysis presented above, it can be inferred that the exposures of 3700 operators to inhalable dust and nickel are acceptable.**

Additive exposures were also found to be well below the acceptable limit for 3700 operators (see Table 24).

#### **Refinery – 3700 Furnace Operators**

For the same reason as detailed for 3500 operators, more than six inhalable dust results are included in this study. Each of these samples was further analysed for nickel. From these results, and the statistical summaries provided in Tables 17a and 18, the following points can be made:

1. No inhalable dust results exceeded the exposure standard, however three nickel results were either equal to or in excess of the 0.9 mg/m<sup>3</sup> exposure standard.
2. The arithmetic means for inhalable dust and nickel were both below the exposure standard. The arithmetic mean's one side 95% upper confidence limit was also below the exposure standard for inhalable dust, but was above the standard for nickel. This means that it can not be stated with 95% confidence that the arithmetic mean exposure for nickel is below the standard.
3. The percentage of results exceeding the exposure standard was less than 5% for inhalable dust, however the percentage for nickel was calculated to be 18%.
4. GSD's for both inhalable dust and nickel were below three indicating that the level of variability is acceptable.

**From the analysis presented above, it can be inferred that the exposures of 3700 operators to inhalable dust is acceptable, however their exposures to nickel are unacceptable. At present these exposures are being controlled via the use of respiratory protection.**

The additive exposure calculation of 0.79 is only just below the acceptable standard of 1 (see Table 24). This is due to the elevated nickel exposures, and further highlights the need for exposure controls.

### **Refinery – Packaging Operators**

For the same reason as detailed for 3500 operators, more than six inhalable dust results are included in this study. Each of these samples was further analysed for nickel and cobalt. From these results, and the statistical summaries provided in Tables 17b, 18 and 19, the following points can be made:

1. All inhalable dust results were found to be below the exposure standard as was the arithmetic mean and the arithmetic mean's one sided 95% upper confidence limit.

2. One nickel result was found to exceed the exposure standard, however the arithmetic mean and the arithmetic mean's one sided 95% upper confidence limit were both found to be below the exposure standard.
3. Three cobalt results were found to exceed the exposure standard of 0.05 mg/m<sup>3</sup>, and the arithmetic mean exposure was only marginally below the standard. The arithmetic mean's one side 95% upper confidence limit could not be calculated as the exposures did not fit either a normal or log-normal distribution. Several elevated cobalt results are believed to have been associated with the drumming of cobalt powders.
4. The predicted percentage of results exceeding the exposure standard was less than 5% for inhalable dust and nickel. The calculated percentage for nickel was 3.5% so it is only marginally acceptable. Such a value could not be calculated for cobalt as the exposures did not fit either a lognormal or normal distribution
5. GSD's were acceptable for inhalable dust and nickel, but were above three for cobalt. The reason for the high cobalt GSD is that packaging operators do not always package cobalt, and as a result, several cobalt exposures were found to be less than the limit of detection (i.e. a high level of variability occurs when these low results are combined with the higher results obtained from monitoring during which cobalt packaging was occurring). This SEG should therefore be split into two – one SEG for when packagers work with both nickel and cobalt, and one SEG in which they only package nickel.

**From the analysis presented above, it can be inferred that the exposures of Packaging Operators to inhalable dust is acceptable, the exposures to nickel are only marginally acceptable and require continued vigilance, and their exposures to cobalt are unacceptable. At present, operator exposures are being controlled via the use of respiratory protection. In order to get a more accurate picture of exposures it is recommended that this SEG be split into two as was outlined above.**

Additive exposures are above the acceptable value due to the unacceptable exposures to cobalt (see Table 24).

### **Refinery – 3800 Operators**

For the same reason as detailed for 3500 operators, more than six inhalable dust results are included in this study. Each of these samples was further analysed for cobalt. From these results, and the statistical summaries provided in Tables 17b and 19, the following points can be made:

1. All inhalable dust results were found to be below the exposure standard as was the arithmetic mean and the arithmetic mean's one sided 95% upper confidence limit.
2. Eleven of the twenty results were either equal to or in excess of the 0.05 mg/m<sup>3</sup> exposure standard for cobalt. As a result, the arithmetic mean exposure of 0.15 mg/m<sup>3</sup> was also greater than the exposure standard.
3. The predicted percentage of results which would exceed the exposure standard was less than 5% for inhalable dust, but 49% for cobalt.
4. The GSD for inhalable dust was acceptable, however the calculated value of 4.5 for cobalt was well above the acceptable value of 3. The reasons for this variability are not clear.

**From the analysis presented above, it can be inferred that the exposures of 3800 operators to inhalable dust are acceptable, however their exposures to cobalt are unacceptable. At present these exposures are being controlled via the use of respiratory protection.**

Additive exposures are above the acceptable value due to the unacceptable exposures to cobalt (see Table 24).

### **Refinery – 3900 Operators**

For the same reason as detailed for 3500 operators, more than six inhalable dust results are included in this study. Each of these samples was further analysed for cobalt. From these results, and the statistical summaries provided in Tables 17b, 18 and 19, the following points can be made:

1. All inhalable dust, nickel and cobalt results were below the relevant exposure standards.

2. The arithmetic means for inhalable dust, nickel and cobalt were all below the exposure standard. The arithmetic mean's one side 95% upper confidence limit was also below the exposure standard for inhalable dust. This value could not be calculated for nickel or cobalt as the exposures did not fit either a normal or log-normal distribution.
3. The predicted percentage of results exceeding the exposure standard was less than 5% for inhalable dust. This value could not be calculated for nickel or cobalt as the exposures did not fit either a normal or log-normal distribution.
4. GSD's for inhalable dust, nickel and cobalt were all less than three indicating that the level of variability is acceptable.

3900 Operators were also monitored for total VOC's (Volatile Organic Compounds). The total VOC results were then further broken down into their constituent groupings. From these results, and the statistical summary provided in Table 21, the following points can be made:

1. All total VOC results were well below the exposure standard, as was the arithmetic mean. The arithmetic mean's one sided 95% upper tolerance limit was well above the exposure standard due to an extremely large level of variability in the results. This will be discussed below.
2. The predicted percentage of total VOC results to exceed the exposure standard was calculated to be less than 5%.
3. The GSD was extremely high indicating a large degree of variability. Further work could be conducted to determine the reasons for this variability, however due to the fact that all of the results were so far below the exposure standard this would not be a high priority.
4. The major constituent of concern within the total VOC mix is naphthalene. Of the six samples only one recorded a result greater than the detection limit, and this result was well below the exposure standard. Small amounts of toluene were also detected, but again, these were well below the exposure standard.

**From the analysis presented above, it can be inferred that the exposures of 3900 operators to inhalable dust, nickel and VOC's are acceptable.**

Additive exposures were also found to be well below the acceptable limit for 3900 operators (see Table 24).

### **Refinery – 5900 Operator**

Only six inhalable dust samples were used in this study, as 5900 Operators were not included in previous sampling programs within the Refinery. From these results, and the statistical summary provided in Table 17b, the following points can be made:

1. All results were well below the inhalable dust exposure standard of 9 mg/m<sup>3</sup>.
2. Both the arithmetic mean and the arithmetic mean's one sided 95% upper confidence limit were well below the exposure standard.
3. The predicted percentage of inhalable dust results which would exceed the exposure standard was well below 5%.
4. The GSD was below 3 indicating that the level of variability within the results is acceptable.

5900 Operators were also monitored for ammonia using data logging instrumentation. From these results, and the statistical summary provided in Table 20, the following points can be made:

1. Ammonia was detected in every sample, and all exposures were found to be below both the TWA and STEL exposure standards.
2. The arithmetic mean exposure and the one sided 95% upper confidence limit were both found to be below the TWA exposure standard.
3. High short term concentrations of up to 97 ppm were recorded during certain high exposure tasks. These high concentrations however, did not cause the STEL exposure standard to be exceeded on any occasion. The high exposure tasks were investigated and found to be associated with the release of ammoniated water and the unloading of ammonia trucks. Respiratory protection was being used to control exposures. Area 5900 also has area alarms which warn of high ammonia concentrations.

**From the analysis presented above, it can be inferred that the exposures of 5900 operators to inhalable dust is acceptable. The greatest risk health risk**



**posed to these operators is exposure to high short-term concentrations of ammonia. The process of identifying high exposure activities therefore needs to be continuous to ensure that appropriate control measures are put in place prior to work commencing.**

Additive exposures for 5900 operators were calculated to be less than the acceptable standard of 1 (see Table 24).

### **General Discussion on Unacceptable SEGs**

The unacceptable SEGs were found to be as follows:

1. 3100 Operators – Inhalable Dust
2. 3700 Furnace Operators – Nickel
3. Packaging Operators – Cobalt
4. 3800 Operators – Cobalt

Each of the above SEGs now requires further study to identify potential control options. Work has been done on several of these SEGs, however before this is discussed in more detail, it is worthwhile reviewing a basic occupation hygiene principal – all control measures should be looked at in terms of the hierarchy of control. This hierarchy states that the following controls should be considered. These are in order of preference:

- Elimination of the process, equipment, or material giving rise to the exposure;
- Substitution with a less hazardous process, equipment or material;
- Engineering controls (eg. Process modification, enclosure, exhaust ventilation, shielding, damping);
- Work practice controls and employee training;
- Administrative controls;
- Proper selection, fitting, and use of personal protective equipment.

(Mulhausen & Damiano, 1998, p. 156)

This hierarchy is based upon the observation that “control of substances in the workplace can be achieved either at the source, in the path from the source to the receiver (exposed worker) or at the receiver” (Deakin University, 1996, p. 7). Control at the source is recommended, whilst control at the receiver is the least acceptable.

This hierarchy is supported as follows by regulation 9.12 of the Mines Safety and Inspection Regulations 1995:

9.12 (1) The principal employer at, and the manager of, a mine must ensure that -

(a) so far as is practicable, the level of atmospheric contaminants at a workplace in the mine is controlled by –

(i) a suppression, ventilation or exhaust extraction system that effectively reduces, dilutes or extracts the contaminants; or

(ii) some other suitable means; and

(b) if it is not practicable to comply with paragraph (a), suitable respiratory protective equipment of a standard not less than that specified in AS 1715 is provided to employees in the relevant workplace.

("Mines Safety and Inspection Regulations," 1995 (WA), r. 9.12 (1).)

In the case of 3700 Furnace Operators, Packaging Operators and 3800 Operators the high exposures are all occurring inside either the nickel packaging shed or the cobalt packaging shed. Before entry into either of these sheds, it is mandatory to wear a P2 respirator. In order to move away from the use of respirators, it will be necessary to implement controls which are higher up the hierarchy. Some extractive ventilation systems are present in both packaging sheds however improvements need to be made. Some work has been done on this and it is recommended that this work continue until improved controls are actually implemented. Until this occurs, the requirement to wear respiratory protection will need to remain in place.

As discussed the unacceptable inhalable dust exposures of 3100 Operators appears to be due to one task, namely cleaning under the sizer. At present this is controlled via the use of P2 respirators. As outlined for the other unacceptable SEG's, work should be conducted to identify controls which rank higher in the hierarchy of control.

### **Recommended Future Sampling Programs**

In order to develop an historical database of exposures, and to ensure that the exposure situation is not changing, it is recommended that monitoring be continued indefinitely. Such monitoring needs to be governed by a specific protocol.

One such protocol has been developed by CEN (European Committee for Standardization, 1995). It is based upon the conclusions drawn from the results of

the initial exposure assessment (i.e. taking sufficient samples within each SEG). If the exposures are well above the standard then the introduction of immediate controls is required, and if the results are well below the standard, then periodic monitoring is not required.

If the results fall between these two extremes, then another sample must be taken within 16 weeks. Depending upon the result of this sample the following occurs:

- If the result is less than  $\frac{1}{4}$  of the exposure standard, another sample must be taken within 64 weeks;
- If the result is between  $\frac{1}{4}$  and  $\frac{1}{2}$  of the exposure standard, another sample is required within 32 weeks;
- If the result exceeds  $\frac{1}{2}$  of the exposure standard, another sample is required in 16 weeks.

Each new sample taken is then compared to these criteria to indicate when the next sample is required (European Committee for Standardization, 1995, p. 26).

An alternative method is the one devised by Roach (Roach, 1977) who provided the following table:

Table 26

*The Minimum Time to be Spent on Regularly Monitoring Personal Exposure*

<b>Man-shifts covered by personal sampling (per 10 employees)<sup>a</sup></b>	<b>Personal exposure/TLV</b>
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1/month	1-2
1/quarter	0.5-1 or 2-4
1/annum	0.1-0.5 or 4-20
None <sup>b</sup>	<0.1 or >20

<sup>a</sup> If there are less than 10 employees in the job under surveillance assume 10

<sup>b</sup> Provided there has been no change of process, material or contaminant control since the last survey

(Roach, 1977, p. 82)

As can be seen, both methods are based upon the principle that further monitoring is not required if exposures are either extremely low or extremely high. However, monitoring frequency increases as the mean exposure approaches the exposure standard. The reasons for this are:

- For extremely low exposures, it is unlikely that any single exposure could exceed the exposure standard;
- For extremely high exposures, it is necessary to immediately implement exposure controls. Only then would further monitoring be required;
- As mean exposures approach the mean, higher sample numbers are required to confidently state whether or not exposures exceed the exposure standard

Table 27 below outlines the additional monitoring required according Roach, as well as what is actually being recommended.

Table 27

*Recommended Future Sampling Program*

<b>Operator type</b>	<b>Roach recommendation</b>	<b>Actual recommendation</b>
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4100/5100 – Hydrogen Sulphide	Not applicable	As required
4100/5100 – Sulphur Dioxide	Not applicable	As required
4100/5100 – Inhalable Dust	1/annum	1/month
4100/5100 – Respirable Dust	None	1/month
3100 – Inhalable Dust	1/annum	1/month
3100 – Sulphuric Acid Mist	1/annum	1/month
3200 – Inhalable Dust	None	1/quarter
3200 – Sulphuric Acid Mist	1/annum	1/quarter
3300 – Inhalable Dust	None	1/quarter
3300 – Sulphuric Acid Mist	1/annum	1/quarter
3400/3510 – Inhalable Dust	None	1/quarter
3400/3510 – Sulphuric Acid Mist	None	1/quarter
3400/3510 – Hydrogen Sulphide	Not applicable	As required
3500 – Inhalable Dust	1/annum	1/quarter
3600 – Inhalable Dust	1/annum	1/quarter
3700 – Inhalable Dust	1/annum	1/quarter
3700 Furnace – Inhalable Dust	1/quarter	1/month
3800 – Inhalable Dust	1/quarter	1/month
Packager – Inhalable Dust	1/quarter	1/month
3900 – Inhalable Dust	1/annum	1/quarter
3900 - VOC	None	1/quarter

<b>Operator type</b>	<b>Roach recommendation</b>	<b>Actual recommendation</b>
5900 – Inhalable Dust	None	1/quarter
5900 – Ammonia	Not applicable	As required

From this table, the following should be noted:

1. Gases are marked as not applicable under the Roach methodology as they are not compatible with random sampling programs;
2. Gases are recommended for monitoring on an “as required” basis, meaning that further work is only required if a problem arises with a specific task or exposure situation;
3. Inhalable dust samples should continue to be analysed for their potential contents. The recommended sampling frequencies are based upon either the worst case constituent of the inhalable dust, or where all constituents have been shown to be present in extremely low concentrations, the inhalable dust result itself.
4. For most operator types, significant historical data did not exist prior to this monitoring program. As a result, sampling frequencies have been increased compared to the Roach methodology to ensure that potential seasonal variations are accounted for. As will be discussed in the following section, the potential for unidentified seasonal variations is one of the weaknesses of this study.
5. For operators found to have unacceptable exposures, monitoring frequencies have been increased compared to the Roach methodology to ensure that these problems are highlighted to management on a regular basis.

The CEN approach was not recommended as the minimum sampling frequency recommended is 16 weeks. With this length of time between samples, potential seasonal variations may still be missed.

If the exposures of any of the various operators were to change dramatically due to the introduction of additional exposure controls or a significant change in the process, then a new monitoring program would need to be implemented. This would involve starting again and taking six samples per SEG.

### **General Discussion on the Success of the Monitoring Program**

1. As was discussed in Chapter 3, a decision was made to make conclusions based on the results of six samples for each SEG. This was considered to be the least number of samples allowable in terms of obtaining valid results. In retrospect, this decision was critical to the success of the monitoring program, as it quickly became apparent that the amount of resistance to wear the sampling equipment was increasing over time. This resistance was mainly associated with a perceived lack of feedback. Although each worker was provided with their individual results within two weeks of being monitored, overall conclusions could not be communicated until the entire sampling program was complete.
2. Due to the fact that the student from ECU was only available for a restricted period of time, this entire monitoring program was completed in approximately four months. The results therefore do not include potential seasonal variations which could be present. If implemented, the recommended future sampling program outlined earlier in this chapter would correct this problem. However, even if there were no restrictions on student availability, it still would have been necessary to quickly gather the required samples to reduce employee resistance as outlined above.
3. By completing the entire monitoring program in a short period of time, management was assured of being informed of the identified problems as soon as was possible.
4. The monitoring program highlighted that random monitoring programs are not compatible for contaminants with short term health effects, or for contaminants in which exposures are unpredictable. Such contaminants should ideally be assessed via the use of instrumentation with data logging facilities, such as that used for hydrogen sulphide and sulphur dioxide. The benefit of this form of monitoring is that the data can then be analysed and

high exposures can be discussed with the operator. Not only does this provide an extremely quick form of feedback to the operator, but it identifies tasks for which exposure controls are required. Procedures can then be implemented to ensure that these controls are in place every time the task is repeated.

5. The monitoring program was successful in identifying the SEGs in which exposures are considered to be adequately controlled. Such information is vital as it can be used to immediately address the concerns to operators. Not only can this reduce the potential for industrial action, it also reduces the amount of reactive work conducted in response to these concerns. This in turn can increase the time available to work on the significant issues, and may also have the added benefit of increasing the level of trust between operators, the Safety, Health and Environment Department and management.
6. A major success of the study was the use of the monitoring logsheets. These sheets were developed with input from operators from each area of the plant. In the past, generic sheets have been used and operators have been asked to write down what tasks they performed at the end of the day. The major drawback of this was that the quality of information received varied greatly from operator to operator. By using the sheets shown in Appendix A, operators were able to provide the necessary details simply and quickly. This information proved to be invaluable in terms of identifying potential high exposure tasks and how often they were occurring, eg. the exposures of 3100 operators to inhalable dust and the exposures of 4100/5100 operators to hydrogen sulphide and sulphur dioxide.
7. The results of this study provide management with an opportunity to negotiate with the DOCEP as to what an appropriate CONTAM quota would be. As discussed earlier, the current CONTAM quota is not reflective of the risks present on site.
8. There is now an opportunity to expand upon this work and include contractors, and those involved in maintenance activities in future hazard identification and monitoring programs.



9. The results of this study are only applicable to the time during which they were obtained. In the future, workplace conditions will change as new hazards are introduced and existing hazards are controlled. This means that the process of hazard identification needs to be continuous, and the components of monitoring programs need to be regularly reviewed.

In conclusion, the results of this study provide a much more detailed understanding of the level of health risks posed to production operators at Murrin Murrin. Armed with this information, management can now accurately and confidently direct resources at exposure controls.

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## APPENDIX A – MONITORING LOGSHEETS



### Monitoring Log Sheet – 3100 Operator

#### Sampling Pump Identification:

**Date:**

**Date of Birth:**

(Required for Government reporting)

**Name:**

**Job title:**

**Employee ID No:**

**Sample Start Time:**

**Sample Finish Time:**

***Please tick the boxes below for the tasks you conducted:***

<b>1. Walk-around checks</b>	<input type="checkbox"/>
<b>2. Bob-catting</b>	<input type="checkbox"/>
<b>3. Hosing down</b>	<input type="checkbox"/>
<b>4. Sampling</b>	<input type="checkbox"/>
<b>5. Screen checks</b>	<input type="checkbox"/>
<b>6. Hosing sizer tunnel</b>	<input type="checkbox"/>

Any additional tasks performed (eg: autoclave demisting/stack fallout):

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## Monitoring Log Sheet – 3200 Operator

### Sampling Pump Identification:

**Date:**

**Date of Birth:**

(Required for Government reporting)

**Name:**

**Job title:**

**Employee ID No:**

**Sample Start Time:**

**Sample Finish Time:**

**Please tick the boxes below for the tasks you conducted:**

<b>1. Walk-around checks</b>	
<b>2. Bob-catting</b>	
<b>3. Hosing down</b>	
<b>4. Isolations</b>	
<b>5. Blown Vent Lines</b>	
<b>6. Depressurisation of GEHO</b>	

Any additional tasks performed (eg: autoclave demisting/stack fallout):

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## **Monitoring Log Sheet – 3300 Operator**

### **Sampling Pump Identification:**

**Date:**

**Date of Birth:**

(Required for Government reporting)

**Name:**

**Job title:**

**Employee ID No:**

**Sample Start Time:**

**Sample Finish Time:**

**Please tick the boxes below for the tasks you conducted:**

1. Sampling circuit	
2. Hosing	
3. General clean-up	
4. Isolations	
5. Bob-catting	
6. General maintenance	
7. Tails inspections	

**Any additional tasks performed (eg: autoclave demisting/stack fallout):**

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## **Monitoring Log Sheet – 3400/3510 Operator**

### **Sampling Pump Identification:**

**Date:**

**Date of Birth:**

(Required for Government reporting)

**Name:**

**Job title:**

**Employee ID No:**

**Sample Start Time:**

**Sample Finish Time:**

**Please tick the boxes below for the tasks you conducted:**

<b>1. Clean and check sample trap 3400</b>	
<b>2. Sampling</b>	
<b>3. Check K/Pot 3510</b>	
<b>4. General checks 3400</b>	
<b>5. General checks 3510</b>	
<b>6. Dam checks</b>	

**Any additional tasks performed (eg: autoclave demisting/stack fallout):**

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## **Monitoring Log Sheet – 3500 Operator**

### **Sampling Pump Identification:**

**Date:**

**Date of Birth:**

(Required for Government reporting)

**Name:**

**Job title:**

**Employee ID No:**

**Sample Start Time:**

**Sample Finish Time:**

**Please tick the boxes below for the tasks you conducted:**

<b>1. Sampling round (venting)</b>	<input type="checkbox"/>
<b>2. Repulping of mixed sulphide bags</b>	<input type="checkbox"/>
<b>3. Repulping of crushed scale</b>	<input type="checkbox"/>
<b>4. General isolations</b>	<input type="checkbox"/>
<b>5. Housekeeping, hosing etc</b>	<input type="checkbox"/>
<b>6. General checks</b>	<input type="checkbox"/>

**Any additional tasks performed:**

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## **Monitoring Log Sheet – 3600 Operator**

### **Sampling Pump Identification:**

**Date:**

**Date of Birth:**

(Required for Government reporting)

**Name:**

**Job title:**

**Employee ID No:**

**Sample Start Time:**

**Sample Finish Time:**

**Please tick the boxes below for the tasks you conducted:**

1.Filled bulky bags from 3700 to 3600	
2.General clean up	
3.Normal operating duties	
4. Hosing area	

**Any additional tasks performed:**

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## **Monitoring Log Sheet – 3700 Furnace Operator**

### **Sampling Pump Identification:**

**Date:**

**Date of Birth:**

(Required for Government reporting)

**Name:**

**Job title:**

**Employee ID No:**

**Sample Start Time:**

**Sample Finish Time:**

**Please tick the boxes below for the tasks you conducted:**

1.Checking pug mills	
2.Cleaning pug mills	
3.Emptying power drums	
4.Emptying bag of chips	
5.Checking/cleaning of screens on rotary filters	
6.Sweeping	
7.Vacuming	
8.Shovelling	
9.Collecting samples for lab	
10.Manual bagging-out from bins	
11.General checks	
12.General isolations	

**Any additional tasks performed:**

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## **Monitoring Log Sheet – 3800 Operator**

### **Sampling Pump Identification:**

**Date:**

**Date of Birth:**

(Required for Government reporting)

**Name:**

**Job title:**

**Employee ID No:**

**Sample Start Time:**

**Sample Finish Time:**

**Please tick the boxes below for the tasks you conducted:**

1. Sample round- tanks, briquette, Co power, autoclaves	
2. Hamer blind changes	
3. Pug mill/ Briquette machine cleaning/monitoring	
4. Pan filter start/stop/monitoring	
5. Feed prep circuit start/stop	
6. Autoclave tasks	
7. Catalyst make-up	

**Any additional tasks performed:**

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## **Monitoring Log Sheet – 3900 Operator**

### **Sampling Pump Identification:**

**Date:**

**Date of Birth:**

(Required for Government reporting)

**Name:**

**Job title:**

**Employee ID No:**

**Sample Start Time:**

**Sample Finish Time:**

**Please tick the boxes below for the tasks you conducted:**

<b>1. Sampling</b>	
<b>2. General clean-up</b>	
<b>3. Control room</b>	
<b>4. Back flush pumps</b>	
<b>5. Walk-around (organic/aqueous checks)</b>	

**Any additional tasks performed:**

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## **Monitoring Log Sheet – 4100-5100 Acid & H2S Plant Operator**

### **Sampling Pump Identification:**

**Date:**

**Date of birth:**

(required for Government reporting)

**Name:**

**Job title:**

**Employee ID No:**

**Sample Start Time:**

**Sample Finish Time:**

**Please tick the box below for the tasks you conducted:**

### **Acid Plant – Area 4100**

1. Sulphuric Acid Samples		10. Emptying Acid Container from Knock Out Pots into Strong Acid Sump	
2. Sulphuric Filter Precoating		11. Decanting Bulkies	
3. DE Addition to Precoat Pit		12. Stack Drain	
4. Sulphur Filter Cleaning		13. Sulphur Stockpile	
5. Sulphur pH Samples		14. Sulphuric Acid Tank Changeovers	
6. Sulphur Samples		15. Pressure Survey	
7. Cleaning Check on Sulphur Conveyor (41-CV-01) Head Chute		16. Stick Testing	
8. Knock Out Pot Draining on North and South Sides of Cold Interpass Heat Exchanger		17. Acid Plant Start-up	
9. Knock Out Pot Draining on 4A Economiser		18. Acid Plant Shut-down	

### **H<sub>2</sub>S Plant – Area 5100**

20. Blowdown Vessel Drain		22. Scuttling Recirc p/ps	
21. H <sub>2</sub> S Cooler Change Over			

Any additional tasks performed:

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## **Monitoring Log Sheet – 5900 Operator**

### **Sampling Pump Identification:**

**Date:**

**Date of Birth:**

(Required for Government reporting)

**Name:**

**Job title:**

**Employee ID No:**

**Sample Start Time:**

**Sample Finish Time:**

**Please tick the boxes below for the tasks you conducted:**

1. Rectify positive pressure in dryer – blow dust out of feed chute	
2. Ammonia release top TK-12	
3. Collecting samples from salt shed	
4. Loading hopper with F.E.L in salt shed	
5. Sample (TK-12, 01, 02)	
6. Line up of CF- 01	

**Any additional tasks performed:**

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## APPENDIX B – UTILITIES MONITORING RESULTS

Explanatory notes for all tables are included at the end of the appendix.

Table 28

*Inhalable Dust Results for 4100/5100 Operators*

Date	Shift	Inhalable dust (mg/m <sup>3</sup> )	Sulphur (mg/m <sup>3</sup> )	Calcium hydroxide (lime) (mg/m <sup>3</sup> )
7/4/02	Day	1.2		
8/4/02	Day	1.7		
24/4/03	Day	1.4	<0.01	<0.2
3/5/03	Night	0.8	0.01	<0.2
13/8/03	Night	1.4	0.05	<0.2
21/9/03	Night	1	<0.01	<0.2
24/1/04	Night	0.7	0.17	0.2
<b>Exposure Standard<sup>a</sup></b>		<b>9</b>	<b>None Available</b>	<b>4.5</b>

Table 29

*Respirable Dust Results for 4100/5100 Operators*

Date	Shift	Respirable dust (mg/m <sup>3</sup> )	Quartz (mg/m <sup>3</sup> )	Cristobalite (mg/m <sup>3</sup> )
20/10/02	Day	0.1	<0.01	
24/2/03	Day	<0.1	<0.01	
27/6/03	Night	0.7	<0.01	<0.02
6/9/03	Day	0.2	<0.01	<0.02
10/9/03	Night	<0.1	<0.01	<0.02
18/12/03	Day	<0.1	<0.01	<0.02
2/3/04	Day	<0.1	<0.01	<0.02
<b>Exposure Standard<sup>a</sup></b>		<b>4.5</b>	<b>0.18</b>	<b>0.09</b>

Table 30

*Sulphuric Acid Mist Results for 4100/5100 Operators*

<b>Date</b>	<b>Shift</b>	<b>Sulphuric acid mist (mg/m<sup>3</sup>)</b>
15/1/04	Day	<0.05
9/2/04	Day	<0.05
19/2/04	Night	<0.05
3/3/04	Day	<0.05
14/3/04	Day	<0.05
25/3/04	Day	<0.05
<b>Exposure Standard<sup>a</sup></b>		<b>0.5</b>

Table 31

*Hydrogen Sulphide Results for 4100/5100 Operators*

<b>Date</b>	<b>Shift</b>	<b>TWA<sup>b</sup> (ppm)</b>	<b>STEL<sup>c</sup> (ppm)</b>	<b>Peak<sup>d</sup> (ppm)</b>
10/1/04	Day	<1	2	43
24/1/04	Day	<1	<1	2
3/2/04	Night	<1	<1	55
3/4/04	Day	<1	<1	7
<b>Exposure Standard<sup>a</sup></b>		<b>5</b>	<b>15</b>	<b>None Available</b>

Table 32

*Sulphur Dioxide Results for 4100/5100 Operators*

<b>Date</b>	<b>Shift</b>	<b>TWA<sup>b</sup> (ppm)</b>	<b>STEL<sup>c</sup> (ppm)</b>	<b>Peak<sup>d</sup> (ppm)</b>
1/2/04	Day	<0.1	0.2	13.8
20/2/04	Day	<0.1	1.5	41
16/3/04	Night	<0.1	0.3	7
26/3/04	Day	<0.1	<0.1	0.5
2/4/04	Night	<0.1	<0.1	<0.1
8/4/04	Night	<0.1	<0.1	<0.1
<b>Exposure Standard<sup>a</sup></b>		<b>1</b>	<b>5</b>	<b>None Available</b>

*Note*, < = result was less than the limit of detection.

<sup>a</sup> Exposure Standard - an airborne concentration of a particular substance, which according to current knowledge, should not cause adverse health effects nor cause undue discomfort to nearly all workers. These standards have been adjusted to account for a 2&2 roster.

<sup>b</sup> TWA (Time Weighted Average) – average airborne concentration of a particular substance when calculated over a normal eight-hour working day, for a five-day working week.

<sup>c</sup> STEL (Short Term Exposure Limit) – a 15 minute time weighted average exposure which should not be exceeded at any time during a working day.

<sup>d</sup> Peak – the highest concentration recorded during the monitoring period.

## APPENDIX C – ORE LEACH MONITORING RESULTS

Explanatory notes for all tables are included at the end of the appendix.

Table 33

*Inhalable Dust Results for 3100 Operators*

<b>Date</b>	<b>Shift</b>	<b>Inhalable dust (mg/m<sup>3</sup>)</b>	<b>Nickel (mg/m<sup>3</sup>)</b>	<b>Cobalt (mg/m<sup>3</sup>)</b>	<b>Copper (mg/m<sup>3</sup>)</b>	<b>Mercury (mg/m<sup>3</sup>)</b>	<b>Chromium (mg/m<sup>3</sup>)</b>	<b>Zinc (mg/m<sup>3</sup>)</b>	<b>Arsenic (mg/m<sup>3</sup>)</b>	<b>Sulphur (mg/m<sup>3</sup>)</b>
10/1/04	Day	7.3	<0.01	<0.01	<0.01	<0.001	<0.01	<0.01	<0.001	<0.01
25/1/04	Day	3.5	0.05	<0.01	<0.01	<0.001	<0.01	<0.01	0.004	<0.01
29/2/04	Night	0.7	<0.01	<0.01	<0.01	<0.001	<0.01	<0.01	<0.001	0.01
1/3/04	Day	1.3	<0.01	<0.01	<0.01	<0.001	<0.01	<0.01	<0.001	<0.01
13/3/04	Night	9.3	0.12	0.01	0.01	<0.001	<0.05	0.01	<0.005	0.12
18/3/04	Night	0.5	0.02	<0.01	<0.01	<0.001	<0.05	<0.01	<0.005	0.01
<b>Exposure Standard<sup>a</sup></b>		<b>9</b>	<b>0.9</b>	<b>0.05</b>	<b>0.9</b>	<b>0.013</b>	<b>0.45</b>	<b>None Available</b>	<b>0.05</b>	<b>None Available</b>

Table 34

*Sulphuric Acid Mist Results for 3100 Operators*

<b>Date</b>	<b>Shift</b>	<b>Sulphuric acid mist (mg/m<sup>3</sup>)</b>
31/1/04	Night	0.1
3/2/04	Night	<0.05
4/2/04	Day	<0.05
17/2/04	Day	<0.05
20/2/04	Day	0.15
18/3/04	Day	<0.05
<b>Exposure Standard<sup>a</sup></b>		<b>0.5</b>

Table 35

*Inhalable Dust Results for 3200 Operators*

<b>Date</b>	<b>Shift</b>	<b>Inhalable dust (mg/m<sup>3</sup>)</b>	<b>Nickel (mg/m<sup>3</sup>)</b>	<b>Cobalt (mg/m<sup>3</sup>)</b>	<b>Copper (mg/m<sup>3</sup>)</b>	<b>Mercury (mg/m<sup>3</sup>)</b>	<b>Chromium (mg/m<sup>3</sup>)</b>	<b>Zinc (mg/m<sup>3</sup>)</b>	<b>Arsenic (mg/m<sup>3</sup>)</b>
12/1/04	Day	0.5	<0.01	<0.01	<0.01	<0.001	<0.01	<0.01	<0.001
13/1/04	Night	0.7	<0.01	<0.01	<0.01	<0.001	<0.01	<0.01	<0.001
15/1/04	Night	0.2	<0.01	<0.01	<0.01	<0.001	<0.01	<0.01	<0.001
23/1/04	Day	0.5	<0.01	<0.01	<0.01	<0.001	<0.01	<0.01	<0.001
2/2/04	Night	0.8	<0.01	<0.01	<0.01	<0.001	<0.01	<0.01	<0.001
9/3/04	Night	0.4	<0.01	<0.01	<0.01	<0.001	<0.01	<0.01	<0.001
<b>Exposure Standard<sup>a</sup></b>		<b>9</b>	<b>0.9</b>	<b>0.05</b>	<b>0.9</b>	<b>0.013</b>	<b>0.45</b>	<b>None Available</b>	<b>0.05</b>

Table 36

*Sulphuric Acid Mist Results for 3200 Operators*

<b>Date</b>	<b>Shift</b>	<b>Sulphuric acid mist (mg/m<sup>3</sup>)</b>
16/1/04	Day	<0.05
17/1/04	Day	<0.05
26/1/04	Night	<0.05
31/1/04	Night	<0.05
14/2/04	Day	0.17
5/4/04	Day	<0.05
<b>Exposure Standard<sup>a</sup></b>		<b>0.5</b>

Table 37

*Inhalable Dust Results for 3300 Operators*

<b>Date</b>	<b>Shift</b>	<b>Inhalable dust (mg/m<sup>3</sup>)</b>	<b>Nickel (mg/m<sup>3</sup>)</b>	<b>Cobalt (mg/m<sup>3</sup>)</b>	<b>Copper (mg/m<sup>3</sup>)</b>	<b>Mercury (mg/m<sup>3</sup>)</b>	<b>Chromium (mg/m<sup>3</sup>)</b>	<b>Zinc (mg/m<sup>3</sup>)</b>	<b>Arsenic (mg/m<sup>3</sup>)</b>	<b>Calcium carbonate (mg/m<sup>3</sup>)</b>
14/1/04	Day	0.2	<0.01	<0.01	<0.01	<0.001	<0.01	<0.01	<0.001	<0.3
24/1/04	Night	0.7	<0.01	<0.01	<0.01	<0.001	<0.01	<0.01	<0.001	<0.3
27/1/04	Day	0.8	0.01	<0.01	<0.01	<0.001	<0.01	<0.01	<0.001	
29/1/04	Day	0.3	<0.01	<0.01	<0.01	<0.001	<0.01	<0.01	<0.001	
3/3/04	Night	<0.1	<0.01	<0.01	<0.01	<0.001	<0.01	<0.01	<0.001	<0.3
9/3/04	Night	<0.1	<0.01	<0.01	<0.01	<0.001	<0.01	<0.01	<0.001	<0.3
11/3/04	Night	0.3	<0.01	<0.01	<0.01	<0.001	<0.01	<0.01	<0.05	<0.3
<b>Exposure Standard<sup>a</sup></b>		<b>9</b>	<b>0.9</b>	<b>0.05</b>	<b>0.9</b>	<b>0.013</b>	<b>0.45</b>	<b>None Available</b>	<b>0.05</b>	<b>9</b>



Table 38

*Sulphuric Acid Mist Results for 3300 Operators*

<b>Date</b>	<b>Shift</b>	<b>Sulphuric acid mist (mg/m<sup>3</sup>)</b>
22/1/04	Night	<0.05
5/2/04	Night	<0.05
11/2/04	Night	<0.05
28/2/04	Day	0.2
1/3/04	Day	0.06
15/3/04	Day	<0.05
<b>Exposure Standard<sup>a</sup></b>		<b>0.5</b>

Table 39

*Inhalable Dust Results for 3400 / 3510 Operators*

<b>Date</b>	<b>Shift</b>	<b>Inhalable dust (mg/m<sup>3</sup>)</b>	<b>Nickel (mg/m<sup>3</sup>)</b>	<b>Cobalt (mg/m<sup>3</sup>)</b>	<b>Copper (mg/m<sup>3</sup>)</b>	<b>Mercury (mg/m<sup>3</sup>)</b>	<b>Chromium (mg/m<sup>3</sup>)</b>	<b>Zinc (mg/m<sup>3</sup>)</b>	<b>Arsenic (mg/m<sup>3</sup>)</b>	<b>Calcium carbonate (mg/m<sup>3</sup>)</b>
30/1/04	Day	0.9	<0.01	<0.01	<0.01	<0.001	<0.01	<0.01	<0.001	<0.3
17/3/04	Day	<0.1	<0.01	<0.01	<0.01	<0.001	<0.01	<0.01	<0.05	<0.3
25/3/04	Day	0.8	0.01	<0.01	<0.01	<0.001	<0.01	<0.01	<0.05	0.1
2/4/04	Night	0.6	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.005	0.1
4/4/04	Night	0.7	0.01	<0.01	<0.01	<0.001	<0.01	<0.01	<0.005	0.2
5/4/04	Day	0.8	0.01	<0.01	<0.01	<0.001	<0.01	<0.01	<0.005	0.2
<b>Exposure Standard *</b>		<b>9</b>	<b>0.9</b>	<b>0.05</b>	<b>0.9</b>	<b>0.013</b>	<b>0.45</b>	<b>None Available</b>	<b>0.05</b>	<b>9</b>

Table 40

*Sulphuric Acid Mist Results for 3400 / 3510 Operators*

<b>Date</b>	<b>Shift</b>	<b>Sulphuric acid mist (mg/m<sup>3</sup>)</b>
12/1/04	Night	<0.05
17/1/04	Day	<0.05
3/2/04	Night	<0.05
5/2/04	Night	<0.05
14/3/04	Day	<0.05
24/3/04	Day	0.1
<b>Exposure Standard<sup>a</sup></b>		<b>0.5</b>

Table 41

*Hydrogen Sulphide Results for 3400 / 3510 Operators*

<b>Date</b>	<b>Shift</b>	<b>TWA<sup>b</sup> (ppm)</b>	<b>STEL<sup>c</sup> (ppm)</b>	<b>Peak<sup>d</sup> (ppm)</b>
24/1/04	Night	<1	<1	<1
30/1/04	Day	<1	<1	<1
3/2/04	Day	<1	<1	<1
4/3/04	Day	<1	<1	<1
17/3/04	Night	<1	<1	<1
18/3/04	Day	<1	<1	1
<b>Exposure Standard<sup>a</sup></b>		<b>5</b>	<b>15</b>	<b>None Available</b>

*Note*, < = result was less than the limit of detection.

<sup>a</sup> Exposure Standard - an airborne concentration of a particular substance, which according to current knowledge, should not cause adverse health effects nor cause undue discomfort to nearly all workers. These standards have been adjusted to account for a 2&2 roster.

<sup>b</sup> TWA (Time Weighted Average) – average airborne concentration of a particular substance when calculated over a normal eight-hour working day, for a five-day working week.

<sup>c</sup> STEL (Short Term Exposure Limit) – a 15 minute time weighted average exposure which should not be exceeded at any time during a working day.

<sup>d</sup> Peak – the highest concentration recorded during the monitoring period.

## APPENDIX D – REFINERY MONITORING RESULTS

Explanatory notes for all tables are included at the end of the appendix.

Table 42

*Inhalable Dust Results for 3500 Operators*

<b>Date</b>	<b>Shift</b>	<b>Inhalable dust (mg/m<sup>3</sup>)</b>	<b>Nickel (mg/m<sup>3</sup>)</b>	<b>Cobalt (mg/m<sup>3</sup>)</b>
14/11/02	Night	0.3	0.06	<0.01
15/11/02	Day	0.4	0.04	<0.01
18/11/02	Day	1	0.21	0.02
21/11/02	Day	1.4	0.25	0.02
22/11/02	Night	0.3	0.03	<0.01
1/12/02	Day	1.5	0.23	0.02
5/12/02	Night	0.5	0.06	<0.01
11/12/02	Day	0.6	0.09	0.01
11/12/02	Night	0.7	0.08	<0.01
13/12/02	Night	0.6	0.04	<0.01
15/12/02	Day	0.5	0.03	<0.01
15/6/03	Day	1.4	0.39	0.03
17/7/03	Day	1.5	0.39	0.03
27/7/03	Day	0.7	0.24	0.02
7/8/03	Night	1.4	0.26	0.02
2/11/03	Day	0.3	0.03	<0.01
31/1/04	Day	0.5	0.11	<0.01
14/3/04	Day	5.2	1.6	0.12
2/4/04	Day	0.5	0.03	<0.01
<b>Exposure Standard<sup>a</sup></b>		<b>9</b>	<b>0.9</b>	<b>0.05</b>

Table 43

*Inhalable Dust Results for 3600 Operators*

<b>Date</b>	<b>Shift</b>	<b>Inhalable dust (mg/m<sup>3</sup>)</b>	<b>Nickel (mg/m<sup>3</sup>)</b>	<b>Cobalt (mg/m<sup>3</sup>)</b>
14/11/02	Night	0.4	0.02	<0.01
15/11/02	Day	0.3	0.01	<0.01
22/11/02	Night	<0.01	<0.01	<0.01
28/11/02	Night	0.8	0.09	<0.01
5/12/02	Night	3.4	0.06	<0.01
11/12/02	Day	0.5	0.04	<0.01
11/12/02	Night	0.7	0.03	<0.01
14/12/02	Night	1.4	0.04	<0.01
16/12/02	Day	0.1	0.01	<0.01
23/12/02	Day	0.5	0.03	<0.01
2/05/03	Day	0.2	<0.01	<0.01
19/06/03	Day	0.9	0.01	<0.01
2/07/03	Day	0.4	0.06	<0.01
27/07/03	Day	0.4	0.04	<0.01
7/08/03	Night	2.8	0.32	0.03
24/1/04	Night	0.8	0.03	<0.01
28/2/04	Day	0.2	<0.01	<0.01
29/2/04	Night	0.2	0.01	<0.01
<b>Exposure Standard<sup>a</sup></b>		<b>9</b>	<b>0.9</b>	<b>0.05</b>

Table 44

*Inhalable Dust Results for 3700 Operators*

<b>Date</b>	<b>Shift</b>	<b>Inhalable dust (mg/m<sup>3</sup>)</b>	<b>Nickel (mg/m<sup>3</sup>)</b>
17/11/02	Day	1.6	0.22
18/11/02	Day	0.9	0.04
21/11/02	Day	0.6	0.03
21/11/02	Night	0.9	0.38
5/12/02	Night	0.4	0.03
10/12/02	Day	0.4	0.09
11/12/02	Night	2.2	0.12
14/12/02	Night	1	0.22
16/12/02	Day	0.4	0.02
19/12/02	Day	0.5	0.12
15/06/03	Day	0.9	0.12
29/07/03	Night	1.1	0.23
23/08/03	Day	0.9	0.19
13/10/03	Night	0.8	0.02
7/11/03	Day	0.7	0.04
8/2/04	Night	0.8	0.07
14/3/04	Day	0.2	0.03
16/3/04	Night	0.3	0.11
<b>Exposure Standard<sup>a</sup></b>		<b>9</b>	<b>0.9</b>

Table 45

*Inhalable Dust Results for 3700 Furnace Operators*

<b>Date</b>	<b>Shift</b>	<b>Inhalable dust (mg/m<sup>3</sup>)</b>	<b>Nickel (mg/m<sup>3</sup>)</b>
14/11/02	Night	0.7	0.38
17/11/02	Day	0.4	0.07
21/11/02	Day	1.3	0.51
22/11/02	Night	0.7	0.58
28/11/02	Night	1.6	1.1
5/12/02	Night	1	0.69
10/12/02	Day	1	0.63
11/12/02	Day	2.3	0.13
11/12/02	Night	3.2	0.23
15/12/02	Day	0.7	0.34
19/04/03	Day	1.9	0.21
17/07/03	Day	1.2	0.61
29/07/03	Night	1.3	0.68
5/09/03	Night	0.6	0.33
11/09/03	Night	1.3	0.89
21/09/03	Day	0.7	0.23
8/10/03	Night	5.7	3.3
3/11/03	Night	0.9	0.3
23/1/04	Day	1	0.23
3/2/04	Day	1.2	0.9
20/2/04	Day	1.4	0.39
1/3/04	Night	0.5	0.06
<b>Exposure Standard<sup>a</sup></b>		<b>9</b>	<b>0.9</b>

Table 46



*Inhalable Dust Results for Packaging Operators*

<b>Date</b>	<b>Shift</b>	<b>Inhalable dust (mg/m<sup>3</sup>)</b>	<b>Nickel (mg/m<sup>3</sup>)</b>	<b>Cobalt (mg/m<sup>3</sup>)</b>
14/11/02	Night	0.7	0.19	0.01
15/11/02	Day	0.9	0.06	0.34
17/11/02	Day	0.8	0.06	0.01
18/11/02	Day	2	0.07	0.34
21/11/02	Day	0.6	0.12	<0.01
22/11/02	Night	0.6	0.2	<0.01
28/11/02	Night	0.7	0.23	<0.01
10/12/02	Day	1.4	0.06	<0.01
11/12/02	Night	0.9	0.17	<0.01
14/12/02	Night	0.5	0.18	<0.01
4/05/03	Night	0.6	0.12	0.12
19/06/03	Day	0.5	0.11	<0.01
2/07/03	Day	0.5	0.12	<0.01
27/07/03	Day	0.9	0.54	0.01
7/08/03	Night	0.5	0.03	0.02
23/08/03	Day	1.1	0.39	0.02
3/11/03	Day	1	0.4	<0.01
20/11/03	Day	1.5	1.1	<0.01
1/2/04	Night	0.1	0.11	<0.01
13/3/04	Night	0.3	0.04	<0.01
1/3/04	Night	1.2	0.73	<0.01
1/4/04	Night	0.9	0.13	0.01
<b>Exposure Standard<sup>a</sup></b>		<b>9</b>	<b>0.9</b>	<b>0.05</b>

Table 47

*Inhalable Dust Results for 3800 Operators*

<b>Date</b>	<b>Shift</b>	<b>Inhalable dust (mg/m<sup>3</sup>)</b>	<b>Cobalt (mg/m<sup>3</sup>)</b>
16/11/02	Night	0.6	0.05
17/11/02	Day	0.8	0.06
18/11/02	Day	0.7	0.07
21/11/02	Day	0.6	0.02
28/11/02	Night	1.5	0.32
11/12/02	Day	1.4	0.05
13/12/02	Night	1.6	0.5
14/12/02	Night	0.2	0.02
15/12/02	Day	0.2	<0.01
30/12/02	Day	0.4	0.02
19/04/03	Day	0.4	<0.01
17/07/03	Day	0.7	0.12
5/09/03	Night	0.3	0.07
9/09/03	Day	0.4	<0.01
11/09/03	Day	0.8	0.28
11/09/03	Night	0.4	<0.01
7/11/03	Day	1.4	0.52
19/2/04	Night	0.6	0.06
9/3/04	Night	1	0.28
17/3/04	Night	0.3	<0.01
<b>Exposure Standard<sup>a</sup></b>		<b>9</b>	<b>0.05</b>

Table 48

*Inhalable Dust Results for 3900 Operators*

<b>Date</b>	<b>Shift</b>	<b>Inhalable dust (mg/m<sup>3</sup>)</b>	<b>Nickel (mg/m<sup>3</sup>)</b>	<b>Cobalt (mg/m<sup>3</sup>)</b>
28/11/02	Night	0.4	<0.01	<0.01
5/12/02	Night	0.3	<0.01	<0.01
10/12/02	Day	0.3	0.01	<0.01
11/12/02	Day	0.4	0.02	<0.01
13/12/02	Night	0.6	0.03	<0.01
14/12/02	Night	0.4	0.02	0.01
16/12/02	Day	0.9	0.07	0.03
18/12/02	Night	1	0.02	<0.01
23/12/02	Day	0.3	0.02	<0.01
23/12/02	Day	0.5	0.03	0.01
4/05/03	Night	0.2	<0.01	<0.01
19/06/03	Day	0.5	0.04	<0.01
29/07/03	Night	0.3	<0.01	0.02
23/08/03	Day	0.3	<0.01	<0.01
11/09/03	Night	0.1	<0.01	<0.01
11/09/03	Day	0.2	0.02	<0.01
3/11/03	Night	0.6	0.07	<0.01
24/1/04	Day	0.5	0.01	<0.01
29/2/04	Day	0.7	0.03	<0.01
13/3/04	Night	0.2	<0.01	<0.01
15/3/04	Night	0.1	0.01	<0.01
<b>Exposure Standard<sup>a</sup></b>		<b>9</b>	<b>0.9</b>	<b>0.05</b>

Table 49

*Solvent Results for 3900 Operators*

<b>Date</b>	<b>Shift</b>	<b>Total VOC<sup>b</sup> (mg/m<sup>3</sup>)</b>	<b>Benzene (mg/m<sup>3</sup>)</b>	<b>Toluene (mg/m<sup>3</sup>)</b>	<b>Ethyl benzene (mg/m<sup>3</sup>)</b>	<b>Xylenes (mg/m<sup>3</sup>)</b>	<b>C6 – C9 (as C7) (mg/m<sup>3</sup>)</b>	<b>C10 – C14 (as C10) (mg/m<sup>3</sup>)</b>
11/1/04	Day	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
31/1/04	Day	5.8	<0.1	1.6	<0.1	<0.1	3.1	2.7
4/2/04	Night	20	<0.1	0.7	<0.1	<0.1	20	<0.1
12/2/04	Night	<0.1	<0.1	0.4	<0.1	<0.1	<0.1	<0.1
14/2/04	Night	0.2	<0.1	0.8	<0.1	<0.1	0.2	<0.1
15/2/04	Day	0.1	<0.1	0.7	<0.1	<0.1	0.1	<0.1
<b>Exposure Standard<sup>a</sup></b>		<b>175</b>	<b>1.6</b>	<b>95</b>	<b>217</b>	<b>175</b>	<b>None Available</b>	<b>26<sup>c</sup></b>

Table 50

*Inhalable Dust Results for 5900 Operators*

<b>Date</b>	<b>Shift</b>	<b>Inhalable dust (mg/m<sup>3</sup>)</b>	<b>Ammonium Sulphate (mg/m<sup>3</sup>)</b>
10/3/04	Night	0.4	0.16
18/3/04	Day	0.6	0.33
3/4/04	Night	0.9	0.32
4/4/04	Day	0.6	0.13
6/4/04	Day	0.2	<0.04
8/4/04	Night	0.2	<0.04
<b>Exposure Standard<sup>a</sup></b>		<b>9</b>	<b>None available</b>

Table 51

*Ammonia Results for 5900 Operators*

<b>Date</b>	<b>Shift</b>	<b>TWA<sup>d</sup> (ppm)</b>	<b>STEL<sup>e</sup> (ppm)</b>	<b>Peak<sup>f</sup> (ppm)</b>
7/2/04	Night	3	17	22
14/2/04	Day	3	6	14
16/2/04	Night	5	5	97
20/2/04	Day	7	16	86
14/3/04	Night	4	7	19
17/3/04	Night	7	14	31
<b>Exposure Standard<sup>a</sup></b>		<b>13</b>	<b>35</b>	<b>None Available</b>

*Note*, < = result was less than the limit of detection.

<sup>a</sup> Exposure Standard - an airborne concentration of a particular substance, which according to current knowledge, should not cause adverse health effects nor cause undue discomfort to nearly all workers. These standards have been adjusted to account for a 2&2 roster.

<sup>b</sup> Total VOC = total Volatile Organic Compounds

<sup>c</sup> This is the exposure standard for naphthalene which is a component of the solvent used in Area 3900. It fits into the C10-C14 category of VOC's.

<sup>d</sup> TWA (Time Weighted Average) – average airborne concentration of a particular substance when calculated over a normal eight-hour working day, for a five-day working week.

<sup>e</sup> STEL (Short Term Exposure Limit) – a 15 minute time weighted average exposure which should not be exceeded at any time during a working day.

<sup>f</sup> Peak – the highest concentration recorded during the monitoring period.